TECHNICAL REPORT 091

A Systematic Review of Stand-level Forest Management for Enhancing and Recruiting Spotted Owl Habitat in British Columbia

2015

BRITISH COLUMBIA

091

A Systematic Review of Stand-level Forest Management for Enhancing and Recruiting Spotted Owl Habitat in British Columbia

Brian D'Anjou, F. Louise Waterhouse, Melissa Todd, and Paul Braumberger

BRITISH COLUMBIA

The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the Government of British Columbia of any product or service to the exclusion of any others that may also be suitable. Contents of this report are presented for discussion purposes only. Funding assistance does not imply endorsement of any statements or information contained herein by the Government of British Columbia. Uniform Resource Locators (URLs), addresses, and contact information contained in this document are current at the time of printing unless otherwise noted.

ISBN 978-0-7726-6890-5 – Print version
ISBN 978-0-7726-6891-2 – Digital version

Citation
D'Anjou B., F.L. Waterhouse, M. Todd, and P. Braumberger. 2015. A systematic review of stand-level forest management for enhancing and recruiting Spotted Owl habitat in British Columbia. Prov. B.C., Victoria, B.C. Tech. Rep. 091. www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr091.htm

Prepared by
Brian D'Anjou
Brian Danjou Forest Services
West Vancouver, B.C.

F. Louise Waterhouse and Melissa Todd
B.C. Ministry of Forests, Lands
and Natural Resource Operations
Coast Area Research Section
Nanaimo, B.C.

Paul Braumberger
B.C. Ministry of Forests, Lands
and Natural Resource Operations
Chilliwack Natural Resource District
Chilliwack, B.C.

Copies of this report may be obtained, depending on supply, from:
Crown Publications, Queen's Printer
2nd Floor, 563 Superior Street
Victoria, BC V8W 9V7
1-800-663-6105
www.crownpub.bc.ca

For information on other publications in this series, visit www.for.gov.bc.ca/scripts/hfd/pubs/hfdcatalog/index.asp.

© 2015 Province of British Columbia
When using information from this report, please cite fully and correctly.

Habitat management for the endangered Northern Spotted Owl (*Strix occidentalis caurina*) was initiated in 1997 in British Columbia's Chilliwack Natural Resource District and the Sea to Sky[1] Natural Resource District under the Spotted Owl Management Plan (SOMP). This plan was revised in 2009. The 1997 plan is now commonly referred to as SOMP1; the newer 2009 revision is referred to as SOMP2.

Under SOMP1, Spotted Owl habitat was managed on a stand-level basis within Spotted Owl Resource Management Zones, where operational guidelines for two forest-management approaches—light volume removal and heavy volume removal—were used. Under SOMP2, Spotted Owl habitat is managed as Long-Term Owl Habitat Area or as Managed Future Habitat Area. Best management practices and General Wildlife Measures within Wildlife Habitat Areas, designated under the *Forest and Range Practices Act*, describe two stand-level forest management approaches. Habitat enhancement practices are designed for application within the Long-Term Owl Habitat Area, and replace light volume removal (SOMP1). Harvest with retention replaced SOMP1 heavy volume removal and is applied within the Managed Future Habitat Area. Under SOMP, wetter and drier ecosystem types are managed slightly differently.

To initiate development of a monitoring framework to assess implementation and evaluate the conservation effectiveness of SOMP habitat management practices, we first reviewed and compared stand-level practices established under SOMP1 and SOMP2 relative to the structural and biological objectives for Spotted Owl habitat. SOMP2 represents an evolution from SOMP1 with the goal of improving Spotted Owl habitat management. Core differences between SOMP1 and SOMP2 practices that are anticipated to influence stand development and habitat quality outcomes are summarized in this report; monitoring to evaluate the structural and biological outcomes of these differences will be vital to evaluating the success of SOMP, and improvements, if any, in the transition from SOMP1 to SOMP2.

SOMP2 habitat enhancement practices have the potential to create a more "natural" canopy gap structural pattern than SOMP1 light volume removal, and a more aggressive retention of large trees. Enhancement of <60-year-old stands (i.e., thinning) practiced under light volume removal is not a focus of habitat enhancement practices, but research indicates that it should be, given the potential for enhanced development of owl habitat attributes when gap creation is combined with thinning. The most significant difference between SOMP2 harvest with retention and SOMP1 heavy volume removal was formalization of the spacing and live-tree density distribution practices under harvest with retention, combined with the shift to retention of veteran trees and live wildlife trees with defects for longer-term future recruitment of snags and downed wood to provide superior habitat. However, the high degree of variability in possible spatial patterns under SOMP approaches may make comparative assessment of these changes difficult, and will require a standardized classification to characterizing patterns of harvest or retention.

1 Formerly called the Squamish Forest District.

To address this variability when evaluating SOMP1 and SOMP2 guidelines and practices, we developed a spatial pattern classification system to describe harvest patterns (for light volume removal and habitat enhancement practices) and retention patterns (for heavy volume removal and harvest with retention) that reflect the habitat management objectives and forest management approaches of SOMP1 and SOMP2. As a first step in monitoring, harvest openings will be classified by spatial pattern, and future field monitoring of habitat attributes will be summarized within these pattern classes.

We then reviewed harvesting implemented under SOMP from 1997 to 2011 to determine the extent of harvesting under each plan, and to begin the preliminary evaluation of harvest practices. A database of individual openings harvested under SOMP1 and SOMP2 was compiled, and a suite of harvest attributes was identified for sub-openings within each opening; each sub-opening was assigned a spatial pattern class. Our review revealed that between 1997 and 2011, 3146 ha (total area under prescription) were managed under SOMP1/SOMP2 guidelines, most of which (92.7%) were harvested under the original Spotted Owl Management Plan (SOMP1). SOMP1 harvesting was largely conducted in drier ecotypes, and heavy volume removal represented the majority of the harvesting implemented under SOMP1. Dispersed retention, alone or in combination with aggregated or group retention, was the most common retention pattern applied and ground-based yarding was the most common logging method used for heavy volume removal. Canopy gaps created by group selection using helicopter logging was the most frequently applied harvesting pattern under SOMP1 light volume removal guidelines, followed by ground-based thinning and tree selection that produced irregular corridors. Very little SOMP2 harvesting had occurred within the review window (1997–2011), all of which was harvest with retention in Managed Future Habitat Areas. Habitat enhancement practices had not yet been applied at the time of this review.

Overall, this comparative review indicated that the transition from SOMP1 to SOMP2 has produced changes and refinements to, and clarifications about, habitat management objectives, forest management approaches, and operational practices and targets. Greater overall knowledge of owl habitat requirements and forest dynamics and succession has, in part, driven these changes and refinements. Of interest is whether these differences in management and eventual outcomes will create significant differences in enhancement and recruitment of stand attributes associated with superior owl habitat, and whether SOMP2 will result in more and better-quality habitat.

Disclaimer

The information and interpretations provided by this systematic review of practices and guidelines under the Spotted Owl Management Plan are intended to support development of a long-term strategy for monitoring Spotted Owl habitat management. Readers should review original cited documents for operational planning and implementation purposes to meet legal and professional requirements.

ACKNOWLEDGEMENTS

We thank the many individuals who have contributed to this project. Jack Sweeten (B.C. Ministry of Forests, Lands and Natural Resource Operations [BCFLNR], Chilliwack Natural Resource District) assisted with project management and data collection. Todd Davis (BCFLNR, Geomatics), with advice from Doug Campbell (BCFLNR, Chilliwack Natural Resource District), produced the original layer of harvest openings from satellite imagery. Mike Smith (BCFLNR, Chilliwack Natural Resource District) provided maps of post-2005 openings using RESULTS. Ralph Schroeder (BCFLNR, Chilliwack Natural Resource District) provided additional information on areas harvested under the Spotted Owl Management Plan (SOMP). Ann Peter and Leonard Feldes (BCFLNR, Chilliwack Natural Resource District) contributed to field reviews. Ian Blackburn provided age class data for SOMP2 Management Areas.

We greatly appreciate the provision of information on areas harvested under SOMP by operators, contractors, and consultants, including B. Blackwell, L. Blackstock, T. Cole, S. Deng, J. Fisher, A. Gabriel, J. Gow, M. Hedberg, A. Hope, D. Horth, J. Howe, J. Iacoviello, J. Jonker, J. Killackey, B. Kyle, J. Noel, J. Pezel, L. Philips, C. Runnals, A. Siemens, L. Stad, E. Stewart, W. Talbot, Chief R. Thevarge, T. Trent, D. Walker, Chief B. Williams, Chief P. Williams, T. Winkle, G. Wolfe, and A. Woods.

Appreciation to all who provided reviews of this document. Reviewers included Jan Jonker, Jack Sweeten, Ann Peter, Greg George, and Roderick Negrave.

CONTENTS

Executive Summary iii

Acknowledgements v

1 Introduction 1
- 1.1 Northern Spotted Owl Habitat Requirements 1
- 1.2 Forest Management to Enhance and Recruit Spotted Owl Habitat 1
  - 1.2.1 Green-tree retention 1
  - 1.2.2 Thinning 4
- 1.3 Stand-level Management of Spotted Owl Habitat in British Columbia 5

2 Management Area 6

3 SOMP1 AND SOMP2: Comparison of Guidelines and Practices 8
- 3.1 Habitat Enhancement Practices and Light Volume Removal 9
  - 3.1.1 Forest management approach 9
  - 3.1.2 Practice comparisons 13
  - 3.1.3 Summary of light volume removal and habitat enhancement practices comparison 19
- 3.2 Harvest with Retention and Heavy Volume Removal 20
  - 3.2.1 Forest management approach 20
  - 3.2.2 Practice comparisons 25
  - 3.2.3 Summary of heavy volume removal and harvest with retention comparison 30

4 A Review of SOMP1 and SOMP2 Implementation 30
- 4.1 Database of Harvest Openings 32
- 4.2 Pattern Classification 33
  - 4.2.1 Harvest pattern classes 33
  - 4.2.2 Retention pattern classes 37
- 4.3 Summary of SOMP1 and SOMP2 Implementation 41

5 Discussion and Conclusions 46
- 5.1 Habitat Management Objectives 47
- 5.2 Light Volume Removal and Habitat Enhancement Practices 48
- 5.3 Heavy Volume Removal and Harvest with Retention 49
- 5.4 Large Woody Debris 51
- 5.5 Summary 51

APPENDICES

1 Wildlife Tree Classification used in Best Management Practices 2009 52

2 List of abbreviations 53

Literature Cited 54

TABLES

1 Stand attribute conditions for superior Spotted Owl habitat in the wetter maritime and drier submaritime ecosystems of British Columbia 2

2 Comparison of habitat enhancement practices and low volume removal by their intended forest management objectives 10

3 Summary of similarities and differences between habitat enhancement practices and low volume removal that are anticipated to affect stand development and Spotted Owl habitat quality outcomes 19

4 Comparison of harvest with retention and heavy volume removal by their intended forest management objectives 21

5 Summary of similarities and differences between harvest with retention and heavy volume removal that are anticipated to affect stand development and Spotted Owl habitat quality outcomes 31

6 Harvesting and silvicultural attributes derived for Spotted Owl Management Plan openings and sub-openings: 1997–2011 32

7 Harvest patterns resulting from the implementation of light volume removal silvicultural systems using three main yarding systems: 1997–2011 36

8 Summary of harvesting under the SOMP1 light volume removal and heavy volume removal, and the SOMP2 harvest with retention in the Chilliwack and Sea to Sky Natural Resource Districts: 1997–2011 42

9 Summary of sub-openings and total net area to be reforested for light volume removal, by district, ecosystem, and harvest pattern class 43

10 Summary of sub-openings and total net area to be reforested for heavy volume removal, by district, ecosystem, and retention pattern class 43

11 Summary of sub-openings and total net area to be reforested for harvest with retention, by district, ecosystem, and retention pattern class 44

12 Summary of the number of heavy volume removal sub-openings by retention pattern class and yarding system 46

FIGURES

1 A 2012 map of the Spotted Owl Management Plan 2 for the Chilliwack Natural Resource District and the Sea to Sky Natural Resource District showing areas designated as Long-term Owl Habitat Area and Managed Future Habitat Area 8

2 Harvest pattern classes for monitoring light volume removal and habitat enhancement practices 34

3 Retention pattern classes for monitoring heavy volume removal and harvest with retention 37

1.1 Northern Spotted Owl Habitat Requirements

The Northern Spotted Owl (*Strix occidentalis caurina*), hereafter referred to as the Spotted Owl, is an endangered species (COSEWIC 2015) in southern British Columbia and the U.S. Pacific Northwest. Habitat loss is a primary threat to Spotted Owl populations (Chutter et al. 2004; COSEWIC 2015; White 2011); therefore, habitat management is key to the survival and recovery of this species (Chutter et al. 2004).

Spotted Owl nesting and foraging habitat is generally described as conifer-dominated maritime and submaritime forests that are at least 100 years old and ≥ 20 m in height, at elevations < 1370 to 1500 m depending on geographic location (SOMIT 1997a; Chutter et al. 2004; Spotted Owl Best Management Practices Working Group 2009). Habitat of superior quality, as defined by its optimal structural composition (Table 1), provides for all of the Spotted Owl's life requisites (nesting, foraging, roosting, and movement). Superior habitat generally occurs in forest stands > 140 years old. Younger stands (100–140 years old, depending on stand origin) can provide lower-quality suitable habitat, which provides some, but not all, life requisites (e.g., foraging and roosting only). Unsuitable stands (< 100 years old) lack the required stand structure, and usually are not used by Spotted Owls.

Managing for prey habitats is integral to managing for Spotted Owl habitat. In British Columbia, Spotted Owl prey include flying squirrels (*Glaucomys sabrinus*), other squirrels (e.g., *Tamiascurus* spp.), deer mice (*Peromyscus maniculatus*), and forest passerines (e.g., Varied Thrush [*Ixoreus naevius*]) (Chutter et al. 2004; D'Anjou et al. 2006). These species are directly affected by stand-level forest management practices.

1.2 Forest Management to Enhance and Recruit Spotted Owl Habitat

The first Spotted Owl conservation strategy for the U.S. Pacific Northwest recognized the potential for silviculture practices to enhance, maintain, and accelerate development of Spotted Owl habitat (Thomas et al. 1990). Retention of live reserve trees (or green trees) in harvested blocks, and management of younger stand development through thinning were identified as options for providing desirable stand habitat attributes over time. The paradigm shift from commodity-based forest management (wood production) to management of forest ecosystems (Haynes 2001), including habitat for the Spotted Owl, was next embedded in the U.S. federal Northwest Forest Plan (USDA and USDI 1994a). The plan mandated the same two broad silvicultural approaches for enhancing Spotted Owl habitat: (1) green-tree retention, and (2) silvicultural thinning or interventions with stand development.

1.2.1 Green-tree retention The concept of "New Forestry," introduced by Franklin (1989), incorporated the retention of green trees (individually and in patches), downed wood, and wildlife trees (including snags [dead trees]) to create structural diversity for wildlife, including the Spotted Owl, within regeneration harvests. The Northwest Forest Plan (USDA and USDI 1994b) specified retention of at least 15% of the area of each cutting unit, with 70% of that in aggregates (0.2–1.0 ha) and the remainder as dispersed trees and clumps (< 0.2 ha). The plan also specified retention of 30–45 trees/ha in areas administered by the Oregon Bureau of Land (USDA and USDI 1994b).

TABLE 1 *Stand attribute conditions for superior Spotted Owl habitat in the wetter maritime and drier submaritime ecosystems of British Columbia (adapted from Spotted Owl Best Management Practices Working Group 2009 and SOMIT 1997b, using the former for most updated information). Bold text indicates differences between wetter and drier ecosystems.*

		Superior habitat condition	
Habitat stand attribute	**Biological function**	**Wetter maritime ecosystem[a]**	**Drier submaritime ecosystem[b]**
Tree canopy closure	Canopy closure maintains thermal cover and regulation, and provides security cover to protect owls from predators	Block-wide average canopy closure >70% (range from 60 to 85%)	Block-wide average canopy closure >70% (range from 60 to 85%)
Horizontal complexity	Horizontal complexity, including gaps, promotes the development of understorey vegetation used by owl prey species (e.g., squirrels and mice) for food, and promotes the development of cover, while enabling the owls to use the adjacent trees for cover when accessing prey in the openings	Horizontal stand complexity created with ≥ three canopy layers (may include a taller shrub layer)	Horizontal stand complexity created with ≥ three canopy layers (may include a taller shrub layer)
Shrubs	The "shrub" layer, or understorey vegetation, provides cover for owl prey species. Shrub species within the understorey provide forage (fungi, seeds, fruit, insects) for owl prey species such as the northern flying squirrel (*Glaucomys sabrinus*).	Understorey vegetation >40% cover, distribution may be patchy. Shrubs represent ≥25% of vegetation cover	Understorey vegetation >40% cover, distribution may be patchy. Shrubs represent ≥25% of vegetation cover
Vertical complexity	Vertical complexity provides multiple canopy layers, and low-lying tree limbs along openings, which are used as perches for hunting and roosting, while layered canopies and canopy lift (height of lowest branches from ground) provide spacing to enable owls to fly through the stand within and under the canopy	Vertical complexity with ≥ three canopy layers (may include tall shrub layer) Presence of tree limbs within 3 m of of the ground along gaps and openings Tree canopy lift of 5 m	Vertical complexity with ≥ three layers (may include tall shrub layer) Presence of tree limbs within 3 m of of the ground along gaps and openings Tree canopy lift of 5 m
Tree height	The density of large trees influences canopy openness and the recruitment of wildlife trees. Owls fly within the canopy between trees and under the canopy. Larger, nesting-diameter trees occur at lower densities and maintain spacing within the stand while providing overhead canopy. Tall, large-diameter trees also promote canopy lift.	Dominant tree height >30 m for nesting and >20 m for foraging and roosting habitat	Dominant tree height >30 m for nesting, and >20 m for foraging and roosting habitat
Large trees	Wildlife trees provide nesting and roosting structures, and eventually, large downed wood. Recruitment relies on the occurrence and longevity of large trees, and thus provides conditions for decay and cavity development.	**Trees >50 cm dbh:** • **average: 200 trees/ha** • **block-wide range: 150–250 trees/ha** **Trees >75 cm dbh:** • **average: 100 trees/ha** • **block-wide range: 37–185 trees/ha**	**Trees >30 cm dbh:** • **average: 240 trees/ha** • **block-wide: 170–310 trees/ha** **Trees >50 cm dbh:** • **average: 100 trees/ha** • **block-wide range: 58–166 trees/ha**

TABLE 1 *continued*

Habitat stand attribute	Biological function	Superior habitat condition	
		Wetter maritime ecosystem[a]	**Drier submaritime ecosystem[b]**
Wildlife trees (Classes 2–7)	Veterans and wildlife trees (usually Classes 2 to 7; Appendix 1) include large trees with defects or snags. They provide cavities (stem or broken top) and large-branch deformities (e.g., Douglas-fir dwarf mistletoe) used as nest structures by owls, and they provide dens for owl prey, such as flying squirrels. Their retention promotes recruitment of downed wood for owl prey habitat.	**Wildlife trees (>75 cm dbh) average ≥10/ha. Tree defects include large cavities, broken tops, dwarf mistletoe infections, and snags.**	**Wildlife trees (>50 cm dbh) average 10/ha. Tree defects include large cavities, broken tops, dwarf mistletoe infections, and snags.**
Tree species	Multiple tree species can promote structural diversity in a stand. Typically, owls are associated with Douglas-fir–dominated stands. Maintaining and promoting Douglas-fir is important because ectomychorrizal associations provide truffles for forage by owl prey (e.g., flying squirrels). Douglas-fir often provides suitable nest structures.	Mixed tree species composition dominated by conifers, with preference for Douglas-fir. May contain a small component of hardwood species.	Mixed tree species composition dominated by conifers, with preference for Douglas-fir. May contain a small component of hardwood species.
Large downed wood	Large downed wood is typically composed of fallen trees, stumps, or fallen large branches (>20 cm diameter) and provides foraging habitat and cover for owl prey species	**Accumulations >250 m^3/ha (range 50–1000 m^3/ha), with a high component >50 cm diameter and >5 m long**	**Accumulations >75 m^3/ha (range 5–1000 m^3/ha) with a high component >30 cm diameter and >5 m long**

a CWHdm, CWHvm1, CWHvm2, and MHmm1 biogeoclimatic subzones (Meidinger and Pojar 1991; Green and Klinka 1994).

b CWHds1, CWH ms1, CWH ms2, MHmm2, ESSFmw, and IDFww biogeoclimatic subzones (Meidinger and Pojar 1991; Green and Klinka 1994).

Support for the use of New Forestry practices to manage Spotted Owl habitat came from studies in the Oregon Cascades, which reported that legacy-rich wind-thrown stands (Carey 1995) and stands with green-tree and snag retention (Carey et al. 1999) support flying squirrel prey populations. Large-scale silvicultural experiments were implemented to formally test the New Forestry retention concepts (D'Anjou 1998, reviewed in Poage and Anderson 2007), but longer-term monitoring, perhaps lasting decades, would be required to assess the implications of developing future owl habitat. However, modelling has been undertaken to assess the implications of green-tree retention, and it has provided more immediate feedback about the effectiveness of New Forestry practices in managing for Spotted Owl habitat. McComb et al. (1993) and Hansen et al. (1995) demonstrated that green-tree and snag retention could enhance the subsequent development of suitable mature forest habitat for Spotted Owl, and that retention densities up to 150 trees/ha in multiple size classes produced stand structures that are typical of natural forests. However, the modelling outcomes, which were corroborated by retrospective field studies, also indicated that green-tree retention could reduce growth of understorey regeneration, particularly that of Douglas-fir, which is important for Spotted Owl; thus, green-tree retention could have implications for the future stand growth rate and tree species composition (Birch and Johnson 1992; Long and Roberts 1992; Rose and Muir 1997; Acker et al. 1998; Zenner et al. 1998). Furthermore, without proactive mitigation, windthrow of retained trees could occur (Stathers et al. 1994; D'Anjou 2007).

1.2.2 Thinning Plantations that lack legacies—that is, those with a closed overstorey canopy in the stem-exclusion phase (Oliver and Larson 1990)—can lack Spotted Owl prey populations (Carey 1995; Carey and Johnson 1995) and structural attributes for roosting, foraging, and nesting (Carey et al. 1992). Reducing tree densities through thinning, combined with longer stand rotations (beyond commercial), was originally suggested as a way to initiate the development of desirable stand attributes for owl habitat, including large trees and understorey vegetation (Thomas et al. 1990; Hunter 1993). Thinning of structurally simple younger forests (<50 years old) produced multi-layered tree canopies, enhanced the development of understorey vegetation and large trees with large crowns, and increased tree crown lengths and the diameter of large branches (Hayes et al. 1997). A common thinning approach used in the United States, termed variable-density thinning, creates tree-free gaps that are integrated with areas of contrasting thinning intensities and with unthinned areas within the same block. This promotes the development of stand heterogeneity that mimics the old-growth patchiness associated with Spotted Owl habitat (Carey at al. 1996). Modelling projections of thinning at various ages (plantations [15 or 30 years old] and natural regenerated stands [>100 years old]) further supported the use of practices that accelerate development of multi-storey structure and large-diameter trees (Barbour et al. 1997).

1.3 Stand-level Management of Spotted Owl Habitat in British Columbia

Based on the two general silvicultural approaches pioneered in the Pacific Northwest, active management of Spotted Owl habitat in coastal British Columbia began in 1997. It was initiated in the Chilliwack Natural Resource District and Sea to Sky Natural Resource District[2] under the first Spotted Owl Management Plan (hereafter referred to as SOMP1) (SOMIT 1997a). Stand-level management guidelines developed under SOMP1 were applied within Special Resource Management Zones (SOMIT 1997a, 1997b, 1999):

- Light volume removal (LVR), including thinning, applied to maintaining a minimum of 67% of the gross forested land as suitable owl habitat within long-term activity centres in Special Resource Management Zones. LVR guidelines prescribed partial harvests—including shelterwood, selection systems, and thinning—that were designed to retain stand integrity and enhance stand structure through the accelerated development of stand attributes associated with owl habitat.
- Heavy volume removal (HVR), with green-tree retention, in Forest Management Areas outside the 67%, focussed on timber production while maintaining owl habitat attributes to provide substitute habitat in the event of catastrophic loss of suitable habitat. HVR guidelines prescribed regeneration harvests—with retention of large trees and minimum amounts of downed wood[3] within designated stand-level reserves dispersed throughout the harvested matrix.

Light volume removal and HVR were expected to improve or recruit suitable habitat for the Spotted Owl at a faster rate than through natural succession, while providing for timber supply (SOMIT 1997b). It was recognized that implementation of the practices under the SOMP1 guidelines would require the use of innovative forestry approaches to account for local stand and site conditions (SOMIT 1999).

Ten years after SOMP1's implementation, Special Resource Management Zones and stand-level management guidelines were revised to provide better habitat protection (Spotted Owl Best Management Practices Working Group 2009). The revised SOMP1 is frequently referred to as SOMP2, which continues to follow the two management approaches of the 1990s. Under SOMP2, Spotted Owl habitat is managed as either Long-Term Owl Habitat Area (LTOHA) or Managed Future Habitat Area (MFHA); best management practices were developed for application within each designation.

The purpose of establishing LTOHAs is to recover and sustain the Spotted Owl population by achieving 100% suitable Spotted Owl habitat conditions within the LTOHA through either conservation of existing habitat or creation of additional habitat (Spotted Owl Best Management Practices Working Group 2009). In contrast, MFHAs are managed primarily for timber harvesting opportunities while maintaining future options for all or portions of the MFHA to become Spotted Owl habitat, if necessary. Best management practices within each designation roughly mirror the two general silvicultural approaches pioneered in the Pacific Northwest and captured in SOMP1:

- Habitat enhancement practices (HEPs) established under the SOMP2 best management practices are permitted within LTOHAs and replace the SOMP1 LVR. HEPs are most appropriate for enhancing the structural

2 Previously called Squamish Forest District.
3 Known operationally as coarse woody debris in British Columbia.

development of 60- to 140-year-old stands through the partial removal of single trees or small groups of trees to improve structural heterogeneity, and thereby improve habitat quality (Spotted Owl Best Management Practices Working Group 2009).

- Harvest with retention (HWR) established under the SOMP2 best management practices replaces the SOMP1 HVR. Retention of structure through HWR in an MFHA is intended to accelerate the development of suitable owl habitat, should that stand be needed in the future to provide habitat, through the retention of structural attributes that will accelerate the development of suitable habitat in regenerating stands.

Following the development of best management practices in 2009, all LTOHAs (except those already included in protected areas and parks) and all MFHAs managed for Spotted Owl under SOMP2 and within the Chilliwack Natural Resource District and Sea to Sky Natural Resource District were legally established as Wildlife Habitat Areas (WHAs) under the *Forest and Range Practices Act* (Province of British Columbia 2002). General Wildlife Measures (GWMs) describe acceptable stand-level retention targets within the WHAs, and are based on the Spotted Owl best management practices for LTOHAs and MFHAs (BCFLNR 2011, 2013).

A comparative assessment of the two separate but related sets of guidelines and practices implemented under SOMP1 (1997–2010) and SOMP2 (2009–present) is required in order to:

- evaluate the implementation and effectiveness of the management of Spotted Owl habitat in British Columbia,
- assess improvements in SOMP2, and
- develop a long-term strategy for monitoring Spotted Owl habitat.

We began the process of evaluation by systematically reviewing and comparing the documented forestry approaches and current practices under SOMP2 with those under SOMP1. We then reviewed SOMP1 and SOMP2 implementation from 1997 to 2011 and characterized the types of harvest and retention practices applied under each plan in order to inform ongoing and future implementation and monitoring of SOMP2, which is now being legally implemented through WHAs and GWMs.

2 MANAGEMENT AREA

The Spotted Owl Management Plan 2 applies to the Spotted Owl range within the Chilliwack Natural Resource District and the Sea to Sky Natural Resource District, both of which are located in the southwest mainland of British Columbia (Figure 1). Most owl habitat within this range is comprised of four biogeoclimatic zones: Coastal Western Hemlock (CWH), Interior Douglas-fir (IDF), Mountain Hemlock (MH), and Engelmann Spruce–Subalpine Fir (ESSF) (Meidinger and Pojar 1991).

The stand-level practices of SOMP1 AND SOMP2 are specified by ecosystem type. Biogeoclimatic subzones and variants were grouped into ecosystem type—that is, "wetter" maritime ecosystems and "drier" submaritime ecosystems—which differ in broad climate, climax forest species, forest develop-

ment, and natural disturbance types (BC MOF and BC MOE 1995b; D'Anjou et al. 2006; Sutherland et al. 2007).

The wetter maritime ecosystems are composed mainly of subzones and variants of the Coastal Western Hemlock zone: the dry maritime subzone (CWHdm, below ~650 m elevation), the submontane variant of the very wet maritime subzone (CWHvm1, below ~650 m elevation), and the montane variant of the very wet maritime subzone (CWHvm2, ~650–1000 m elevation). Wetter maritime ecosystems also occur in the windward variant of the moist maritime subzone of the Mountain Hemlock zone (MHmm1, above ~1000 m elevation). In wetter, lower-elevation maritime ecosystems, including the CWHdm and CWHvm1 subzones (Green and Klinka 1994), forests are typically a mixture of Douglas-fir (*Pseudotsuga menziesii*), western redcedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*). Douglas-fir is less dominant in the vm1 and is usually absent from the higher-elevation, wetter ecosystems, CWHvm2 and MHmm1, which are dominated by western hemlock and mountain hemlock (*Tsuga mertensiana*), amabilis fir (*Abies amabilis*), and yellow-cedar (*Chamaecyparis nootkatensis*).

The drier ecosystems include two subzone variants of the Coastal Western Hemlock: the southern variant of the dry submaritime subzone (CWHds1, below 650 m elevation), and the southern variant of the moist submaritime subzone (CWHms1, ~650–1200 m elevation). The wet warm subzone of the IDF (IDFww, 100–1200 m elevation), although an interior ecosystem, is included in the drier ecosystem types because it is transitional to the maritime ecosystems of the coast. At higher elevations, the leeward variant of the moist maritime subzone occurs in the Mountain Hemlock zone (MHmm2, ~900–1400 m elevation), and the moist warm subzone occurs in the Engelmann Spruce–Subalpine Fir zone (ESSFmw, ~1300–1650 m elevation). In drier, lower-elevation, submaritime ecosystems (CWHds1 CWHms1, CWHms2, and IDFww), forests are typically dominated by Douglas-fir, with western redcedar and western hemlock as the secondary or tertiary species. Douglas-fir is absent from higher elevation zonal ecosystems (ESSFmw and MHmm2) that are comprised of mountain hemlock, subalpine fir, and yellow-cedar.

Stand-initiating events in wetter ecosystems tend to be smaller-scale, rare-to-infrequent events, while those in drier ecosystems are infrequent-to-frequent, stand-maintaining fires (BC MOF and BC MOE 1995b).

Under SOMP2, the LTOHA comprises 29 274 ha in the Chilliwack Natural Resource District and 9676 ha in the Sea to Sky Natural Resource District (Figure 1), of which, 34.1 and 30.7%, respectively, are in the 60- to 140-year age classes most appropriate for HEPs. The Chilliwack Natural Resource District has 23 761 ha of MFHA; the Sea to Sky Natural Resource District has 11 407 ha (Figure 1).

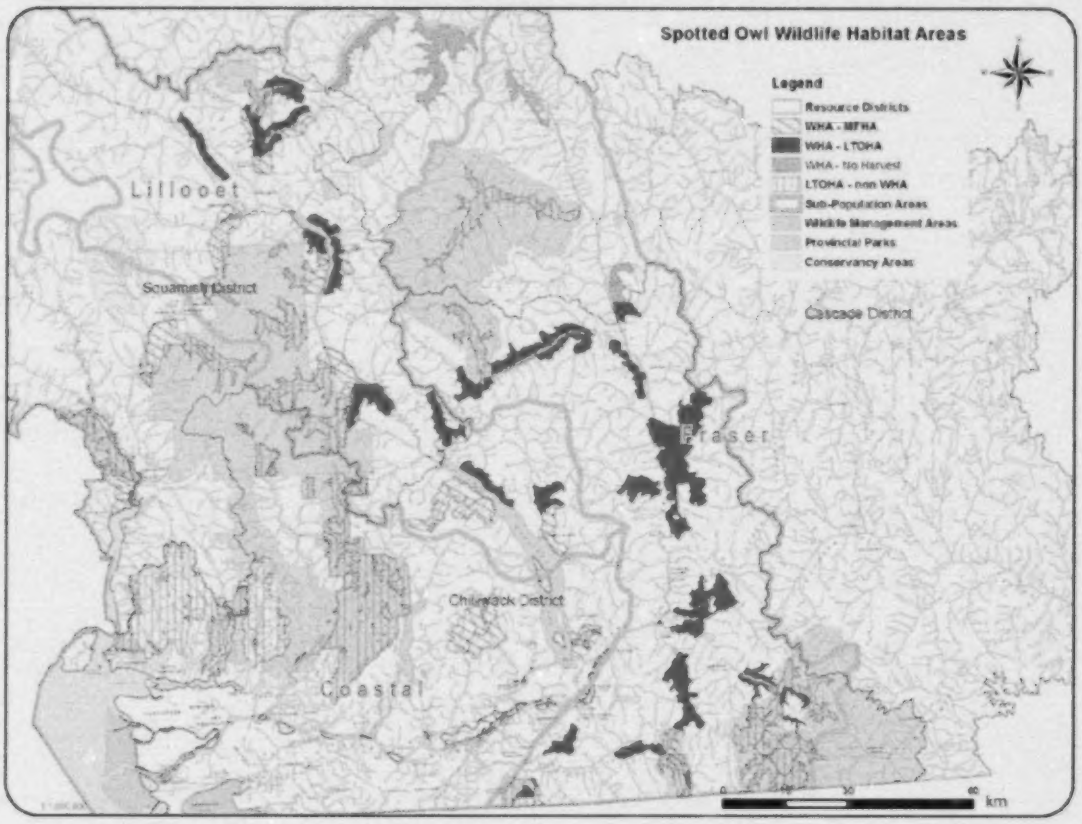


FIGURE 1 *A 2012 map of the Spotted Owl Management Plan 2 for the Chilliwack Natural Resource District and the Sea to Sky Natural Resource District showing areas designated as Long-Term Owl Habitat Area and Managed Future Habitat Area (provided by the British Columbia Ministry of Forests, Lands and Natural Resource Operations, Feb. 3, 2014).*

3 SOMP1 AND SOMP2: COMPARISON OF GUIDELINES AND PRACTICES

Light volume removal under SOMP1 and HEPs under SOMP2 share the goal of improving the quality of Spotted Owl habitat by enhancing stand structure, and thereby expanding the amount of superior habitat in LTOHAs. Heavy volume removal under SOMP1 and HWR under SOMP2 are also intended to achieve the same goal: accelerate the recruitment of suitable habitat in post-harvest regenerating stands through structural retention.

Differences in the guidelines and practices of SOMP1 and SOMP2 are anticipated to result in differences in operational applications (i.e., silvicultural system or stand-tending approach), and therefore in subsequent stand development and long-term outcomes. Of interest is whether these differences in applications and outcomes will produce significant differences in enhancement and recruitment of the stand attributes of superior owl habitat (Table 1), and whether the implementation of SOMP2 guidelines and practices results in more and better-quality habitat.

3.1 Habitat Enhancement Practices and Light Volume Removal

The HEPs in SOMP 2—that is, best management practices (Spotted Owl Best Management Practices Working Group 2009) and GWMs (BCFLNR 2011, 2013)—were reviewed, summarized, and then compared to a similar review and summary of the SOMP1 LVR forest management approaches and guidelines (SOMIT 1997b, 1999). Table 2 presents a comparative summary of the practices intended to produce attribute conditions that promote superior habitat quality (Table 1).

3.1.1 Forest management approach Partial cutting and thinning are prescribed to improve owl habitat suitability by promoting attributes that are typical of mixed-species, later-successional stands that have a multi-layered canopy (SOMIT 2007a, 2007b; Spotted Owl Best Management Practices Working Group 2009). The SOMP1 LVR was designed to accelerate the development of owl habitat through the use of partial cutting, and evolved to include thinning[4] in younger stands (30–80 years old) and selection-system harvesting in mature (80–100 years old) and older stands (>100 years old). Selection harvests were prescribed for mature stands to accelerate development of suitable owl habitat attributes, while their application in older stands aimed to enhance habitat quality from moderate to superior or to allow limited tree removal while maintaining superior habitat quality (SOMIT 1999).

Similarly, HEPs under SOMP2 are prescribed for improving or accelerating the development of superior Spotted Owl habitat attributes but are considered most appropriate for stands in the stem-exclusion stage of development (estimated at 60–140 years old) (Spotted Owl Best Management Practices Working Group 2009; BCFLNR 2011, 2013). Selection harvesting within these mature to older candidate stands should provide opportunities for improving owl habitat suitability by reducing stand density, creating gaps, developing heterogeneity, and accelerating stand development toward late-successional structure. HEPs are expected to produce improvements in habitat suitability within 20 years of application (Spotted Owl Best Management Practices Working Group 2009; BCFLNR 2011, 2013). Late-successional stands exhibiting the attributes of superior owl habitat are not candidates for HEPs. Silviculture systems trials in coastal British Columbia forest ecosystems, including research on group selection treatments in stands of varying age (Hollstedt and Vyse 1997; D'Anjou 2003; de Montigny 2004; de Montigny and Nigh 2009), will provide relevant data on stand and regeneration development. However, these ecosystems and stand types currently under study are different from the stand types associated with Spotted Owl management in British Columbia.

Research that directly monitors the response of Spotted Owls to changing habitat quality associated with different stand-development trajectories created by varying levels of selection and retention is limited (e.g., Meiman et al. 2003; White 2011; Wilson and Forsman 2013); most research has focussed on owl prey response (e.g., Wilson and Forsman 2013). Holloway et al. (2012) suggested that there is a threshold response between flying squirrel abundance and green-tree retention—40–75% retention (using aggregates to groups) in mature Douglas-fir–dominated stands—but response depended on the amount of mature forest in the surrounding landscape. In south-

4 Referred to as commercial thinning in some documents.

central British Columbia, group selection harvests (1-ha openings) in the Engelmann Spruce–Subalpine Fir biogeoclimatic zone had fewer negative effects on small mammal communities than did clearcuts (Ransome et al. 2009). HEPs allow for slightly more basal area removal in mature and older stands than does LVR (40% of total area under prescription for HEPs versus 33% by diameter class for LVR), although HEPs promote smaller canopy gaps than does LVR (Table 2). Regardless, harvest levels and opening sizes for both HEPs and LVR appear to be well below any aforementioned thresholds that might limit prey species availability.

Light volume removal allowed entry for limited timber extraction in late-successional superior habitat stands (>140 years old), while HEPs do not. Entering older Douglas-fir and other superior habitat stands introduces several undesirable consequences, including potential highgrading of the largest trees, incidental loss of veteran trees and snags due to worker safety concerns or other operational limitations, residual tree damage from falling and yarding, wind-caused tree loss, standing tree mortality, and shift of tree species from desired Douglas-fir to more shade-tolerant species (Isaac 1956). Franklin at al. (2002) suggested that harvesting within existing old-growth and late-successional stands may cause stand development to diverge from natural forest structure and function. Furthermore, maintaining intact late-successional stands within the range of the Spotted Owl in British Columbia will provide a benchmark against which to evaluate the performance and effectiveness of HEPs.

TABLE 2 *Comparison of habitat enhancement practices (HEPs) and light volume removal (LVR) by their intended forest management objectives (i.e., superior owl habitat stand attributes [Table 1]). HEPs are summarized from General Wildlife Measures (BCFLNR 2011, 2013) except where an asterisk (*) indicates original guidance from best management practices (Spotted Owl Best Management Practices Working Group 2009). LVR is summarized from Spotted Owl Management Plan 1 (SOMP1) (SOMIT 1997b); an asterisk (*) indicates operational guidelines that focussed on upgrading moderate habitats to superior habitats (SOMIT 1999). Where values for the wetter and drier ecosystems differ, they are indicated as wet or dry.*

Superior habitat stand attributes	**HEPs (SOMP2)**	**LVR (SOMP1)**
Tree canopy closure	Harvest level: • Maximum basal area harvest of 40% for total area under prescription* • Distributed throughout the total area under prescription	Harvest level: • Up to one-third of the basal area from each 10 cm stand diameter class* • Distributed evenly* • Maintain a minimum of 50% (dry) and 60% (wet) crown closure*
Stand horizontal complexity (gaps) Shrubs	Harvest pattern: • Sizes of canopy gaps: • ≥50% of the area as either single stems or groups, resulting in canopy gaps < 50 m^2 (0.005 ha) • ≤25% gaps are 51–300 m^2 (up to 0.03 ha) • ≤25% basal area removed in timber extraction corridors <8 m wide Road rights-of-way: max. 20 m wide	Harvest pattern: • Patch cuts (0.05–0.5 ha) must comprise < 5% of prescribed area; minimum 100 m apart from other openings* • Timber extraction corridor widths are not to exceed average inter-tree spacing requirements (i.e., 3.2–7.6 m)*
Stand vertical complexity (including tall shrubs)	Create gaps to release understorey trees and promote vegetation growth.* Release advanced regeneration and natural ingress to create lower tree layers.*	Allow branch retention within 3 m of ground in at least one-third of the stand. Create or maintain stands that exhibit a multi-layered, variable density, multi-species stand structure with canopies dominated by dominant and co-dominant trees.*

TABLE 2 *Continued*

Superior habitat stand attributes	HEPs (SOMP2)	LVR (SOMP1)
Stand tree height Density of large trees	Maintain a minimum average tree density: • Wet: 225 live trees >50 cm dbh/ha; tree retention may vary between 200 and 250 stems/ha >50 cm dbh • Dry: 275 live trees >30 cm dbh/ha; tree retention may vary between 240 and 310 >30 cm dbh Retain an average of 100 large-diameter trees/ha for the treatment area.[b] (Retention may vary from 50 to 150 trees/ha throughout.) • In non-uniform stands (e.g., naturally regenerated stands), select from the largest 150 trees/ha across the treatment area.[b] • In uniform stands (e.g., plantations), select from the dominant and co-dominant canopy layer across the treatment area. • Distribution of retained large trees should ideally represent a two-thirds retention of the various diameter classes in the largest 150 live trees/ha.*	Retain large trees: • Wet: at least 40 of the largest trees/ha[c] • Dry: at least 200 of the largest trees/ha
Density of wildlife trees (classes 2–7/8)	Wildlife tree density: ≥10 large wildlife trees/ha, if present, retained among the 100 largest trees/ha (see above), across wildlife trees classes 2–7/8 Typical diameters: • Wet: >75 cm dbh • Dry: >50 cm dbh Wildlife Tree Retention Area (WTRA): minimum 10% of the total area under prescription is retained as untreated: • Locate the WTRA to minimize falling of dead wildlife trees (Classes 3–7/8; required by WorkSafeBC).*	Dying trees or snags: maintain or create ≥ 5/ha, on average. Minimum diameter, if available: • Wet: >50 cm dbh • Dry: >30 cm dbh Retain two trees with broken tops per hectare: • Wet: >50 cm dbh • Dry: >30 cm dbh
Tree species composition	No specified practices; species profile is maintained through harvest level, harvest pattern, and large-tree retention practices	Maintain two or three conifer species, plus 6–10 deciduous trees/ha, dispersed throughout the block. Maintain >20% of the stand as Douglas-fir or grand fir because of ectomycorrhizal associations that provide food for primary prey species.
Large downed wood	Retain pre-harvest downed wood. Recruit post-harvest, non-merchantable, large coarse woody debris (CWD; defined as non–self-supporting logs > 7.5 cm diameter small end, branches > 20 cm diameter, and stumps): • distributed across the treatment area, and • not piled at roadsides or landings.	Maintain existing large coarse woody debris. (CWD) Recruit: • Wet: 25 m^3/ha of unmerchantable logs > 50 cm diameter • Dry: 20 m^3/ha of unmerchantable logs > 30 cm diameter

a The total area under prescription includes the treatment area, timber extraction corridors, road rights-of-way, landings, natural non-productive areas (e.g., rocky outcrops, slides, wetlands), and Wildlife Tree Retention Areas and other reserves.

b The treatment area is the area where tree removal occurs; it excludes road rights-of-way (the road prism: edge of cutbank to edge of fill slope), natural non-productive areas, and Wildlife Tree Retention Areas and other reserves.

c SOMP1 management guidelines were difficult to directly interpret against the superior habitat and HEP large-tree densities because the large-tree retention targets appeared low.

Thinning

Thinning, either as a pre-commercial treatment or as applied to older stands as a commercial thin, was a key approach in LVR. HEPs do not preclude candidate stands < 60 years old but do not explicitly focus on thinning. However, the GWMs apply to uniform stands (including structurally simple plantations in the LTOHA). HEPs could be applied to these younger stands, using thinning approaches for improving habitat condition within 20 years.

Most new research on approaches to enhancing forest structure has focussed on thinning of younger stands (30–60 years old) rather than on entries in older mature stands because the maximum stand age permitted for silvicultural activities in Late-Successional Reserves in the U.S. Pacific Northwest is 80 years. Contemporary thinning practices as defined by Anderson and Ronnenberg (2013) incorporate two important concepts. First, old-growth stands originally developed under lower live-tree densities than those in managed, unthinned, young stands. Reducing tree density of second-growth stands by using effectively designed thinning treatments will improve the likelihood that the stand will develop attributes associated with future Spotted Owl habitat. Second, stand attributes associated with late-seral floral and faunal biodiversity—including downed wood, snags, and large older trees (with complex crowns)—can be lacking in plantations, and thinning can protect and recruit these attributes into young managed stands. Variable-density thinning retains structure while lowering stand density (Carey and Johnson 1995). Variable-density thinning, which is designed to focus on retention and development of large trees, snags, and downed wood, could be used under HEPs to shape more innovative thinning treatments for the development of late-successional forest.

Current research supports the application of thinning to achieve owl habitat structure. Modelling studies (TASS modelling of 50-year-old stands) have shown that thinning, including juvenile spacing, of young stands reduces the amount of time required to reach the target mean tree diameters and create larger-diameter branches.[5] Thinning and juvenile spacing promote the structural complexity that leads to late-successional conditions (Garman et al. 2003), including mid-storey development (Wilson and Forsman 2013). Heavy thinning combined with underplanting and additional thinning entries can develop forest patches that are structurally similar to Spotted Owl nest sites (Andrews et al. 2005). The results of silviculture experiments designed to test the assumptions of New Forestry support the use of thinning to enhance structure for owl habitat. Dodson et al. (2012) demonstrated that after 6–11 years, variable-density thinning treatments applied to 40- to 60-year-old Douglas-fir forests (100–300 trees/ha in the thinned portions) had accelerated development of stand heterogeneity and canopy layering. Wilson and Forsman (2013) reported that thinning can release existing suppressed tree cohorts, and thereby enhance lower crown classes desired for owl habitat. Similarly, Comfort et al. (2010) found that variable-density thinning increased the growth of mid-canopy trees, which created greater spatial heterogeneity associated with late-successional forests.

5 D. McLennan and G. Recknell. 1999. Conceptual stand management prescriptions to accelerate the development of desirable old-growth attributes in immature conifer stands. Prepared for B.C. Ministry of Environment, Lands and Parks, Surrey, B.C. Review draft, internal document.

Thinning on its own does little to recruit large snags, particularly in the short term if snags are absent from stands or felled for safety requirements during harvesting (Province of British Columbia 1998b). Topping of trees and inoculation of heart rot fungi in sound trees have been tried experimentally (Manning et al. 2012), but 8 years after treatment, the trees remained sound and showed no evidence of flying squirrel use. However, thinning applied within the practice framework of HEPs would benefit from required retention of large-tree and wildlife-tree densities.

Field studies have also shown that owl prey abundance may be sensitive to thinning, at least in the short term (Verschuyl et al. 2011). In 35- to 45-year-old Douglas-fir plantations, flying squirrel densities were reduced in thinned stands where retention was 125–275 stems/ha, for up to 12 years after treatment (Manning et al. 2012). Retention of untreated forest within thinned stands or the surrounding landscape could mitigate loss of cover (i.e., mid-storey occlusion and connectivity) that Spotted Owls require for security (Manning et al. 2012; Wilson and Forsman 2013). HEPs include at least 60% basal area retention and Wildlife Tree Retention Areas (WTRAs) as untreated areas, and a suite of other practice requirements that could be combined with thinning to promote prey populations and other associated owl habitat attributes.

3.1.2 Practice comparisons There are notable differences between the SOMP1 and SOMP2 practices that are likely to influence stand development outcomes and the associated habitat attribute condition and habitat quality (Table 2). Habitat quality had to be maintained under LVR treatment (SOMIT 1999), but the HEPs treatment objectives are more rigorous; they require habitat quality improvement within 20 years of treatment, in addition to not permitting the quality of one attribute to be reduced in order to improve the quality of another (Spotted Owl Best Management Practices Working Group 2009). In particular, harvest patterns and retention levels for wetter and drier ecosystems are significantly different under SOMP2 than under SOMP1. However, HEPs are designed to be less prescriptive than LVR; the focus is on achieving the GWMs and specified structural outcomes while providing operational flexibility during implementation of the GWMs.

Harvesting patterns

Harvesting patterns within mature stands targeted for enhancement under HEPs will likely differ from those under LVR. HEPs employ a combination of single-stem removal and small-gap creation to achieve suitable and superior owl habitat (Table 2). With a maximum 40% basal area removal, HEPs promote group harvesting, thus mimicking the development of natural canopy gaps (300 m^2 maximum gap areas, or 10 m in diameter; ≥ 50% by area in very small openings ≤ 50 m^2). This represents a form of natural disturbance–based management for the low-disturbance frequency, windward and leeward coastal forests inhabited by Spotted Owls (Spies and Franklin 1991). Natural canopy gap formation results primarily from tree mortality due to root rot and wind damage (Spies et al. 1990; Gray and Spies 1996). HEPs allow for yarding corridors (≤ 25% by area) if they are required for tree removal and/or operational flexibility.

Prescribing a group selection system to enhance stand heterogeneity and development of lower crown classes is well supported by research. Enhanced

regeneration development and growth in harvested gaps compared with unharvested forest have been reported for both old-growth and mature Douglas-fir–dominated stands (Gray and Spies 1996). Similar enhancement of regeneration has been reported for natural gaps in old-growth Douglas-fir stands (Passmore 2007) and stands dominated by old-growth redcedar / western hemlock (Stan and Daniels 2010). Enhanced western hemlock and redcedar growth among canopy and subcanopy trees surrounding natural canopy gaps (120–560 m²), combined with declining tree growth related to increasing distance from gap centres, may result in the development of heterogeneous stands (Stan and Daniels 2014). Gray et al. (2012) experimentally created gaps to demonstrate that canopy gaps can produce heterogeneity due to spatial variation in effects on tree growth and mortality.

In contrast to HEPs, in SOMP1, the LVR practice of removing a maximum of 33% basal area from each diameter class (Table 2), which effectively requires the stand profile be harvested, has resulted in narrow yarding corridors (Section 4). Narrow yarding corridors limit the light that reaches the understorey, the growth response of lower crown classes, and the development of shrubs. The use of narrow yarding corridors also leads to a shortening of the period before crown closure occurs; thus, a second harvest entry is required to maintain the understorey regeneration and vegetation development desired for owl habitat. HEPs, as did LVR, permit subsequent harvest entries for the purpose of directing stand development toward desirable owl habitat structure. The shift from corridor harvesting to gap creation under HEPs may reduce the number of treatments needed to maintain canopy openings that promote the development of attributes that define superior owl habitat. HEPs provide flexibility in creating gaps in specific locations and away from attributes that require protection, such as areas with high densities of wildlife trees and snags.

Harvesting patterns implemented in immature stands under HEPs will also likely differ from those implemented under LVR. Commercial thinning implemented in immature stands under LVR guidelines permitted variable-density thinning (prescribed density ranging from 110 to 220 stems/ha within a 30-year-old stand) and "patch cut" openings (up to 0.5 ha) in order to accommodate harvesting in areas with significant forest health issues (e.g., root rot). HEPs focus on gap development rather than the block-wide thinning promoted under LVR, and maximum gap size is substantially less than the 0.5 ha allowed under LVR. Roberts and Harrington (2008) found that small experimental gaps (400–500 m², 0.04–0.05 ha) created in younger stands led to enhanced growth of trees beside the gap relative to the growth of trees farther away. Within 20-year-old Douglas-fir plantations, Miller et al. (2007) found that gaps created by skid trails during thinning also promoted tree growth. These studies suggest that the creation of canopy gaps, combined with thinning, leads to enhanced tree growth, which in turn is conducive to the development of large-diameter trees and stand heterogeneity, both of which are important stand attributes associated with owl habitat.

Retention levels

Some retention objectives and practices under HEPs and LVR differ by ecosystem type (i.e., wetter and drier), including those for minimum retention densities and diameter distributions of live large trees and wildlife trees (including snags), canopy closure, and large woody debris. Minimum reten-

tion levels changed in the transition from LVR to HEPs; the most significant changes were in the retention of large trees, including wildlife trees, and in large downed wood, all of which were designed to improve outcomes for stand development and habitat quality (Table 2).

Large-tree and wildlife-tree density

The retention of large live trees and wildlife trees for superior owl habitat evolved from LVR to HEPs following the availability of improved data and producing more refined targets. The LVR large-tree density targets were based on inventory from Washington State, and were to be revised when British Columbia data became available (SOMIT 1997b). Live-tree densities prescribed under HEPs reflect recently obtained data that document tree densities within Spotted Owl habitats in British Columbia (Spotted Owl Best Management Practices Working Group 2009).

Light volume removal required the retention of at least two-thirds of the trees/ha by diameter class, while HEPs prescribe specific post-harvest density targets for live trees, with a minimum diameter limit set for wet versus dry ecosystems (Table 2). HEPs targets are consistent with superior owl habitat conditions (Table 1).

In addition to the general two-thirds target, LVR had two separate retention targets for large trees and wildlife trees (Table 2):

- largest trees per hectare (40 for wetter and 200 for drier ecosystems); no diameter at breast height (dbh) or vigour (live or dead) specified; and
- maintenance or recruitment of at least seven wildlife trees/ha (five large dying trees or snags/ha and two large, broken-top trees/ha).

It is unclear if the latter wildlife tree target (two large, broken-top trees/ha) was allowed to contribute to the largest trees per hectare target.

In contrast to the largest tree per hectare targets of LVR, HEPs prescribe the retention of 100 of the 150 largest-diameter live trees per hectare from non-uniform forest or from the dominant and co-dominant canopy layer for uniform forest. The distribution of retained large trees will ideally represent two-thirds retention of the diameter classes within the largest 150 live trees/ha (Spotted Owl Best Management Practices Working Group 2009). Retained trees can include veteran trees and live, healthy wildlife trees (Wildlife Tree Class 1; British Columbia Wildlife Tree Classification; Appendix 1) with valuable habitat characteristics such as large, clustered, or gnarled branches and horizontal branches with moss mats. By defining the retention of the largest trees as a proportion (i.e., of 150), flexibility is provided for prescription development.

Habitat enhancement practices also have a separate target for wildlife-tree retention, which has increased from LVR to the density required for superior owl habitat (Table 1). At least 10 large wildlife trees/ha are to be retained, if present, from among the 100 of the largest 150 live trees (Table 2). These are expected to represent the range of wildlife-tree classes (i.e., Classes 2–7/8, representing the range of dead standing trees based on heart wood decay and standing form and condition [Appendix 1]), which will contribute to the steady recruitment of coarse woody debris (CWD) over time, or emphasize retention of rarer wildlife-tree classes in a landscape (Spotted Owl Best Management Practices Working Group 2009). Yet by definition, only Class 2 wildlife trees—that is, live, unhealthy trees with decay or deformities—fit the

live-tree definition for the 100 of 150 target, whereas Classes 3–7/8 describe dead trees (BC MOF and BC MOE 1995b). Since the 10 large wildlife trees/ha are to come from the 100 of 150 live-tree target, it is unclear how the full range of wildlife-tree classes will be accounted for under HEPs.

The combined changes from LVR to HEPs include specifying post-harvest large live-tree densities by diameter limit at levels consistent with superior owl habitat, structuring the retention of large-diameter trees to better reflect the actual composition of the stand, and increasing wildlife-tree density to reflect superior habitat condition (Table 1). Overall, these HEP changes are expected to result in higher densities of large-diameter trees and wildlife trees (particularly in the wetter ecosystems), with the aims of mitigating any loss of these core structural attributes of superior Spotted Owl habitat while increasing the probability of continued wildlife-tree development through a supply of large-diameter trees.

Under HEPs, wildlife-tree diameters were increased to match those associated with superior habitat (Table 1). The minimum diameter of a wildlife tree increased from 30 to 50 cm dbh for drier ecosystems and from 50 to 75 cm dbh for wetter ecosystems, for LVR versus HEPs, respectively. As noted above, under LVR, minimum densities of wildlife trees were increased from seven (five snags and two broken tops) to 10 wildlife trees/ha (Classes 2–7/8). Under HEPs, higher retention levels of large trees and wildlife trees reflect the importance of very large-diameter wildlife trees, live and dead, in the life history of Spotted Owls. Spotted Owls require large-cavity nesting trees that are usually >100 cm dbh (Forsman and Giese 1997; Waterhouse et al. 2012), and their prey, flying squirrels, use large snags (>eight snags/ha of >40 cm dbh for retaining densities) as nesting sites (Holloway and Smith 2011).

Under HEPs, minimum densities of large trees exceed the averages that describe superior habitat (Table 1), and thus provide a buffer for post-harvest tree loss that might occur due to wind damage or other causes (Spotted Owl Best Management Practices Working Group 2009). Garber et al. (2011) reported that 16% of tree mortality in group selection treatments (0.2-ha openings) was attributed to wind damage, and the annualized mortality rate (0.76%) 13 years after harvest was marginally higher than in the control (0.51%). The HEPs objective of enhancing habitat within 20 years is supported by the higher retention densities; that is, enough large trees are retained to ensure sufficient representation of suitable large-diameter and wildlife trees within the acceptable enhancement period, given expected tree mortality.

The probability of vigorous, large, live trees developing the defects (e.g., broken tops, heart rot, and large cavities) required for superior owl habitat is unknown. However, the recruitment of relatively rare decay features such as large cavities has been investigated. Large cavities require considerable time to develop (Bunnell 2013), which depends on the right combination of decay-influencing factors (e.g., climate, tree species, stand composition, and site factors) (Remm and Lõhmus 2011). Researchers have estimated that only 0.25–1.4% of live trees in Oregon and Washington form a stable cavity of any size (Temesgen et al. 2008), and, in the American Midwest, the probability of a tree having a cavity is higher in old-growth forests than in second-growth forests (Fan et al. 2003). This suggests that a large number of precursor trees is needed in managed forests to increase the chance that one optimal wildlife tree will develop.

Snags are very difficult to retain in managed forests due to concerns about worker safety during harvesting activities. LVR promoted the creation of snag trees of a minimum diameter in order to meet density targets for wildlife trees. In contrast, with HEPs, the future snag supply relies on natural mortality of living wildlife trees; that is, practices emphasize the retention of large live trees and live wildlife trees for snag recruitment. However, HEPs also require that at least 10% of the total area under prescription be retained as untreated WTRAs, and recommend that the WTRAs be located in areas of dead wildlife trees (Classes 3–7/8) in order to buffer and protect the snags from falling, which addresses worker safety.

Although HEPs requirements for retaining large trees are more explicit than those of LVR, they provide more operational flexibility to achieve those objectives. LVR specified minimum densities of large trees on a per-hectare basis, but HEPs specify a block-wide range in large live- and largest-tree densities, which accommodates variability in the distribution of large trees.

Large downed wood

The HEPs General Wildlife Measures define large CWD as non-self-supporting fallen trees or logs >7.5 cm in diameter at the smaller end and angled < 45 degrees to the ground surface, fallen branches with >20 cm diameter, and stumps (BCFLNR 2011, 2013). However, for superior owl habitat, large downed wood is defined by diameter (>50 cm for wetter ecosystems and >30 cm for drier ecosystems) and length (>5 m) (Table 1). These diameters for superior habitat were used to define large CWD for SOMP1 (Table 2). Furthermore, in British Columbia, large CWD is generally defined as ≥ 20 cm dbh and ≥ 10 m long (BCFLNR 2010; Densmore 2011). Under the HEPs best management practices, diameters for large CWD are greater than those recommended for superior owl habitat; that is, 75 cm for wetter ecosystems and 50 cm for drier ecosystems (Spotted Owl Best Management Practices Working Group 2009).

In coastal British Columbia, post-harvest CWD (>7.5 cm diameter) is rarely in short supply, but large CWD is frequently underrepresented, particularly in the wetter ecosystems (e.g., CWHdm, CWHvm) (Densmore 2011). Large pieces of downed wood provide important habitats for Spotted Owl prey (Amaranthus et al. 1994; North et al. 1997; Gomez et al. 2005). The recommended volumes of CWD per hectare for superior owl habitat (75 m^3/ha in drier ecosystems and 250 m^3/ha in wetter ecosystems) aim to capture a sufficient number of large pieces to maintain prey habitat quality, and guidelines specify that a high component of those volumes should be large CWD (Table 1). It will, therefore, be important to monitor the outcomes of the GWMs definition of large CWD.

Light volume removal and HEPs both focus on the retention of all existing pre-harvest CWD (Table 2) to maintain a range of downed wood tree species, decay stages, and size classes (Spotted Owl Best Management Practices Working Group 2009). Under HEPs, pre-harvest CWD will not be assessed as post-harvest waste (BCFLNR 2013).

Light volume removal specified the recruitment of small, fixed volumes of post-harvest unmerchantable large-diameter wood (as defined by superior owl habitat) that were below—and in the case of wetter ecosystems, substantially below—the volumes required to provide superior owl habitat quality (Tables 1 and 2). LVR did not specify log length as an important attribute of large CWD.

Under the best management practices in SOMP2, HEPs prescribe the retention of post-harvest non-merchantable wood when pre-harvest levels are below the recommended volumes per hectare for superior owl habitat (Spotted Owl Best Management Practices Working Group 2009). The GWMs for the LTOHA (i.e., HEPs) require the retention of all pre-harvest CWD, and allow for post-harvest recruitment of CWD. However, the GWMs for LTOHA do not specify post-harvest retention levels except to recommend, in the appendix of one of the Orders, that post-harvest recruitment should occur where pre-harvest levels are <75 m³/ha (Spotted Owl Best Management Practices Working Group 2009).

The HEPs best management practices recommend the retention of large CWD (≥ 20 cm dbh and ≥ 5 m long) and encourage that long pre-harvest and post-harvest pieces be left undamaged (Spotted Owl Best Management Practices Working Group 2009). However, HEPs GWMs, and the appendices describing the intent of the GWMs for CWD retention within the LTOHA, refer to large CWD as defined within the WHA Orders (i.e., logs >7.5 cm diameter at the smaller end). They do not specify large-diameter long pieces as in the best management practices. Post-harvest CWD retained by HEPs is assessed under the *Provincial Logging Residue and Waste Measurement Procedures Manual* (BC MOF 2005).

Unlike LVR, HEPs mandate the retention of 10% of the total area under prescription as WTRAs (Table 2); these untreated areas may act as source pools of large downed wood. A recent review of coastal CWD retention indicated that in the wetter Coastal Western Hemlock variants, Wildlife Tree Patches retained higher percentages of large CWD than did the harvested matrix (Densmore 2011). HEPs also have higher retention requirements for large-tree density than does LVR (BCFLNR 2010), which provides greater opportunity for short-term and long-term recruitment of large CWD.[6] Importantly, while LVR did not address the spatial distribution of CWD, the GWMs in HEPs require pre-harvest and post-harvest CWD to be distributed across the treatment area, not piled at roadsides or landings where it has limited ecological value (BCFLNR 2010, 2011, 2013). The HEP best management practices also recommend the retention of slow-decaying species (e.g., redcedar), if available, in order to provide a longer-lasting supply of downed wood into the future (Spotted Owl Best Management Practices Working Group 2009; BCFLNR 2011, 2013).

Habitat enhancement practices are intended to retain and, if needed, increase amounts of large downed wood, but it is unknown whether actual amounts will differ from that retained through LVR. LVR forced some large CWD retention. HEPs make no such stipulation, but they do create a practice environment that is conducive to the retention of large CWD—that is, all pre-harvest CWD is retained, only 40% of a stand will be treated, 10% of the area treated will be retained as untreated WTRA, retention of large trees for future CWD recruitment is high, and post-harvest CWD may be retained. Given that the pre-harvest volumes of CWD in coastal British Columbia are naturally high, and post-harvest volumes are also typically high (Densmore 2011), the retention of post-harvest CWD volumes required for superior owl habitat should be relatively easy to achieve using the HEPs in SOMP2. Yet, the ability

6 G. Dunsworth, and D. Huggard. 2004. Draft strategy for managing coarse woody debris in coastal British Columbia. B.C. Min. For. Range, For. Pract. Br., Victoria, B.C. Intern. document.

to recruit large CWD will be constrained in younger stands, particularly those in the stem exclusion stage (i.e., small-diameter stems). The future success of retaining large CWD under HEPs is unknown and should be closely monitored.

3.1.3 Summary of light volume removal and habitat enhancement practices comparison The core similarities and differences between HEPs and LVR that are anticipated to influence stand development and habitat quality outcomes are summarized in Table 3. Monitoring the structural and biological outcomes of these differences will be vital to evaluating the success of the SOMP1 LVR, SOMP2 HEPs, and improvements, if any, in the transition from SOMP1 to SOMP2. HEPs appear to create a more "natural" structural pattern and a more aggressive retention of large trees. Practices eliminated in the transition from LVR to HEPs (e.g., retention of low limbs and canopy lift, and tree species composition) (Table 2) are indirectly addressed

TABLE 3 *Summary of similarities and differences between habitat enhancement practices (HEPs) and light volume removal (LVR) that are anticipated to affect stand development and Spotted Owl habitat quality outcomes (SOMP = Spotted Owl Management Plan)*

Guideline and practice	HEPs (SOMP2)	LVR (SOMP1)
Forest management approach		
Operational flexibility	More	Less
Time to habitat improvement	20 years	n/a
Silviculture system	Single-tree selection	Single-tree selection
	Group selection	Group selection
		Thinning (pre-commercial and commercial)
Target treatment stand age[a]	Most appropriate 60–140 years	30–80 years
		80–100 years
		100–140 years
		>140 years
Treatments permitted in late successional stands	Non-superior habitat only[b]	Yes
Harvest level	40% of basal area removal within the total area under prescription	33% of basal area removal
		Basal area removal limited by diameter classes (10-cm classes)
Practice		
Harvest pattern		
Mature forest	"Natural" canopy gaps and linear corridors	Linear corridors
Immature forest	"Natural" canopy gaps and linear corridors	Block-wide thinning
Retention level		
Large tree density	Higher	Lower
Wildlife tree density	More	Less
	Larger-than-superior size classes	Superior size classes
	Wildlife Tree Retention Areas	Snag creation
Large downed wood	Retain all pre-harvest coarse woody debris (CWD)	Retain all pre-harvest CWD
	Potential for non-merchantable, post-harvest large CWD retention, if required	Targets for non-merchantable, post-harvest, large CWD retention

a Does not preclude other ages.

b Treatments must improve habitat quality. Treatments within superior habitat are not permitted because they will not result in a net benefit to owl habitat.

through other aspects of HEPs, and their elimination is not anticipated to cause significant differences in long-term outcomes. HEPs could provide more explicit direction for the enhancement of < 60-year-old stands (i.e., thinning), as was provided under LVR, given the opportunities for successful enhancement highlighted in recent research. The long-term differences in stand development resulting from LVR compared to HEPs warrant exploration through modelling.

3.2 Harvest with Retention and Heavy Volume Removal

The SOMP2 HWR employs harvesting strategies and stand-level retention practices similar to those used in the SOMP1 HVR; both approaches have the same goal. Both HWR and HVR are intended to be applied in areas managed for timber harvesting opportunities, where structural attributes are retained to accelerate the development of superior Spotted Owl habitat attributes in regeneration harvests (Spotted Owl Best Management Practices Working Group 2009; BCFLNR 2011, 2013). These management approaches target retention to promote the accelerated development and recruitment of specific superior habitat stand attributes—large trees, wildlife trees, and large downed wood (Table 1)—that develop naturally over hundreds of years (Franklin et al. 2002). We reviewed the SOMP2 guidance and practices for HWR, as presented in *Best Management Practices for Managing Spotted Owl Habitat* (Spotted Owl Best Management Practices Working Group 2009) and in the *General Wildlife Measures of the Wildlife Habitat Area Orders* (BCFLNR 2011, 2013), and compared them to the earlier guidance given in SOMP1 under HVR (SOMIT 1997b, 1999). Table 4 presents a comparison of HVR and HWR practices that are intended to promote the development of the superior habitat attributes in the regenerating stand.

3.2.1 Forest management approach The SOMP2 HWR and SOMP1 HVR are generally applied to stands that are managed on short rotations, and can be applied to old-growth stands that occur in the SOMP2 MFHA (formerly SOMP1 FMA). Both approaches use reserves[7] to retain, create, and/or allow the development of specific structural attributes that are not necessarily present in stands that are managed on a 60- to 100-year rotation (SOMIT 1997; Spotted Owl Best Management Practices Working Group 2009). SOMP2 (HWR) meets British Columbia's definition of a retention system (Province of British Columbia 1998a):

(a) retain individual trees or groups of trees to maintain structural diversity over the area of the cutblock for at least one rotation, and
(b) leave more than half the total area of the cutblock within 1 tree height from the base of a tree or group of trees, whether or not the tree or group of trees is inside the cutblock.

The Spotted Owl Management Plan 1 HVR can be applied as a clearcut with reserves silvicultural system or a single/group tree retention system.[8]

7 Reserves are retained during harvesting or other forestry operations, and are intended to satisfy management objectives (e.g., provide habitat or other values) for at least one rotation (BC MOF 2003).

8 Under SOMP1 (SOMIT 1997b, 1999), the terminology clearcut with reserve was used, but by definition, HVR may meet a single/group leave-tree retention definition. A clearcut with reserve system is defined as a variation of clearcutting that retains uniformly spaced or small groups of trees for purposes other than regeneration (de Montigny and Nigh 2009).

HWR requires levels of retention (e.g., average of 15 or 40 trees per hectare) distributed over the block to create an edge-effect influence on ≥ 50% of the block (BC MOF 2003). HVR required the same level of retention and promoted a uniform distribution over the block through single/group tree retention. However, HVR also allowed for retention to be located entirely within Wildlife Tree Patches and riparian management areas using a clearcut with reserve system. The main advancement of HWR over HVR is that no point within the block is more than one tree length (40 m) from a retained tree (Table 4). As such, HWR provides clear direction on the expected pattern of distribution, while also allowing for flexibility to aggregate trees.

TABLE 4 *Comparison of harvest with retention (HWR) and heavy volume removal (HVR) by their intended forest management objectives (superior owl habitat stand attributes [Table 1]). HWR practices are based on the General Wildlife Measures (BCFLNR 2011, 2013) except where * indicates original guidance from best management practices (Spotted Owl Best Management Practices Working Group 2009). HVR is summarized from Spotted Owl Management Plan 1(SOMP1) (SOMIT 1997b); an asterisk (*) indicates operational guidelines from SOMP1 (SOMIT 1999). Where values for the wetter and drier ecosystems differ, they are indicated as wet or dry.*

Superior habitat stand attribute	**HWR (SOMP2)**	**HVR (SOMP1)**
Tree canopy closure Stand horizontal complexity (gaps) Shrubs Vertical complexity of stand (including tall shrubs)	A minimum 10% of the total area under prescriptiona is retained as untreated Wildlife Tree Retention Area (WTRA). • Vary sizes of WTRAs. No point within the total area under prescription should be > 40 m from a retained tree; spacing between retained trees is ≤ 80 m. No more than 40% of the large-tree retention can be in WTRA or other reserves. In the treatment area,[b] retain large trees singly or in small clusters (e.g., 5 trees) to maintain structural diversity of large trees within the total area under prescription.*	Minimum 10 % of the total area under prescription in uncut patches as reserve areas (i.e., Wildlife Tree Patches, Riparian Reserve Zones). Maintain or develop at least three canopy layers. Allow branch retention within 3 m of ground for at least one-third of the stand.
Stand tree height Density of large trees	In non-uniform stands (e.g., naturally regenerated with a degree of structural heterogeneity), retain a minimum average of: • Wet: 15 of the 30 largest-diameter live trees/ha • Dry: 40 of the 80 largest-diameter live trees/ha In uniform stands (e.g., plantations), retain a minimum average of: • Wet: 15 large-diameter live trees/ha • Dry: 40 large, large-diameter live trees/ha from the dominant and co-dominant canopy layers Retained trees should be windfirm. Minimum densities of large live trees are achieved by averaging across the entire total area under prescription, but large trees retained per hectare may vary within the total area under prescription. Include any veteran trees and Class 1 wildlife trees that exhibit valuable habitat characteristics.	Retain large, live, healthy, windfirm trees: • Wet: average at least 15 of the top 30* largest-diameter trees/ha • Dry: average at least 40 of the top 80* largest-diameter trees/ha Although it is desirable to maintain an even distribution of leave trees, retention may be in Wildlife Tree Patches and Riparian Reserve Zones located within block boundaries.*

TABLE 4 *Continued*

Superior habitat stand attribute	HWR (SOMP2)	HVR (SOMP1)
Density of wildlife trees (Classes 2 to 7)	Include a significant component of veteran trees and large dominant trees with defects (e.g., cavities, broken tops) in large-tree retention.* Place WTRAs in locations that optimize protection and recruitment of forest structural attributes associated with Spotted Owl habitat.* Place WTRAs in locations that will minimize felling of unsafe dead wildlife trees (Classes 3–7), as per WorkSafeBC requirements.*	Retain two trees > 50* cm dbh with broken tops per hectare. Retain an average of at least five* snags and/or dying trees/ha, and concentrate large snags in reserves: • Wet: snags/ha > 76 cm dbh • Dry: snags/ha > 51 cm dbh May be retained in Wildlife Tree Patches and Riparian Reserve Zones.
Tree species composition	Retain Douglas-fir and western redcedar because these are tree species closely associated with Spotted Owl habitat* and are more windfirm. Plant early-succession conifer species ecologically suited for the site, and consider variable-density planting.	Maintain two to three conifer species, with approximately 6–10 deciduous trees/ha interspersed. Reserve areas should be multi-species, multi-aged, and multi-layered. Concentrate veteran Douglas-fir and grand fir trees in reserve areas.
Large downed wood	Retain large coarse woody debris (CWD) representative of pre-harvest species and sizes. Retain a minimum average of 75 m^3/ha of large CWD over the treatment area. Recruit post-harvest, non-merchantable CWD if there is insufficient pre-harvest large CWD to meet the required minimum average volume (subject to Waste Assessment). Preharvest western redcedar should represent ≥ 25 m^3/ha of the 75 m^3/ha if present; if < 25 m^3/ha is present, all large, pre-harvest, western redcedar CWD should be retained. CWD should be distributed across the treatment area, not piled at roadsides or landings. A variety of types of large CWD (i.e., fallen trees, logs, large branches) should be retained; fresh-cut stumps are not considered CWD unless other types of CWD are limited in the stand. Avoid breaking long, large pieces (> 10 m long, > 20 cm diameter) during operations.*	Maintain existing large CWD on site. Recruit: • Wet: 25 m^3/ha of unmerchantable logs > 50 cm diameter • Dry: 20 m^3/ha of unmerchantable logs > 30 cm diameter • Avoid piling and burning at the roadside; scatter over the site.

a The total area under prescription includes the treatment area, timber extraction corridors, road rights-of-way, landings, natural non-productive areas (e.g., rocky outcrops, slides, wetlands), and WTRAs and other reserves.

b The treatment area is the area where tree removal occurs; it excludes road rights-of-way (the road prism: edge of cutbank to edge of fill slope), natural non-productive areas, and WTRAs and other reserves.

HWR practices also emphasize the role of retention of veterans and live dominant trees with defects for the recruitment of structural attributes that are associated with superior owl habitat. HWR does not focus on dead tree retention over the block, as was prescribed under HVR, because these trees may not necessarily provide long-term structures. HWR does continue to recognize the role of dead trees within Wildlife Tree Retention Areas.

Depending on how they are applied, HWR and HVR may produce dispersed retention patterns similar to those created from seed tree and uniform shelterwood silvicultural systems. These traditional silvicultural systems do not, however, produce long-term heterogeneous patterns that are typical of

natural stands (Franklin et al. 2002). Unlike seed tree or shelterwood systems in which retained trees are cut once the regenerating stand is established (BC MOF 2003), retention under HVR and HWR is designed to be permanent; that is, the trees are retained throughout the rotation in order to maintain or introduce structural heterogeneity in the regenerating stand.

The science supporting green-tree retention, including the changes specified under HWR from HVR to promote structural heterogeneity to recruit future superior owl habitat, remains uncertain. Although modelling and experimental field trials associated with green-tree retention and subsequent stand development studies have been conducted since the 1990s, they have focussed mainly on younger Douglas-fir stands, including both plantations and naturally regenerated stands. Furthermore, research on green-tree retention in mature to old-growth stands has been limited, in part because harvesting has been excluded in >80-year-old forests in late-successional reserves on U.S. federal land within the range of the Northern Spotted Owl (USDA and USDI 1994a). Overall, studies report mixed success in the retention of attributes associated with superior owl habitat (Table 1) and their recruitment into regenerating stands using green-tree retention, and that a number of variables affect outcomes (e.g., site characteristics, retention densities, regeneration, and stand tending practices).

Both modelling and field research studies suggest that green-tree retention may help recruit owl habitat attributes. Modelling of Douglas-fir stand development in western Oregon showed that harvest with 15% canopy cover retention reduces wood production, but when combined with understorey thinning, it allows for the development of large trees, enhanced diversity of canopy height, and enhanced accumulation of woody debris (Busing and Garman 2002), which are all superior owl habitat attributes. Field research conducted by Urgenson et al. (2013) suggests that retention of large-diameter trees in aggregates and reserves, such as in WTRAs, will promote recruitment of the superior habitat attributes of snags and downed dead wood. Notably, HVR allowed for the retention of unsuitable Wildlife Tree Patches and their subsequent enhancement through the application of LVR (Appendix 1 in SOMIT 1999), while HWR targets retention of wildlife trees in areas of high-value habitat attributes. Reserve quality is of primary interest in monitoring and comparing the effectiveness of the SOMP1 HVR and SOMP2 HWR.

An unusual outcome of dispersed retention that may prove beneficial to recruiting owl habitat is the development of epicormic branching by retained Douglas-fir trees— that is, new branching originating from dormant buds— in response to density reduction and increased exposure to sunlight and heat. Epicormic branching has been documented among dispersed retention (Day et al. 2011) and under group selection (Walter and Maguire 2004) as promoting complex crown development that is visually similar to Douglas-fir veterans, and as such, may help recruit desirable owl habitat attributes.

Modelling studies, in some cases supported by field research, have suggested that there are potential problems in relying on green-tree retention for habitat recruitment (but most studies do not consider how multiple entries for stand management could address these problems). The problems include time to recruitment of large structures, stand conversion to shade-tolerant species, and loss of retained structures to windthrow.

Recruitment of stand structures, such as wildlife trees, may prove challenging, especially in younger stands that lack large veteran or deformed trees in the canopy for initial retention. For example, modelling of stand

development to 100 years in dispersed retention stands (40 trees/ha) in the CWHdm showed that snag recruitment was limited to the subcanopy, snags were smaller than those desired for the wetter maritime ecosystems, and tall wildlife trees for nests and roosts were not recruited (D'Anjou et al. 2006). HWR practices will not directly address this problem.

Studies also suggest that retention densities required to promote the development of owl habitat structure may be at odds with regeneration of Douglas-fir, itself a significant attribute of superior owl habitat.

The results of retrospective studies (Rose and Muir 1997; Zenner et al. 1998; Keeton and Franklin 2005) and field research (Smith and Beese 2012; Brodie and DeBell 2013; Urgenson et al. 2012) that investigated the implications of retention on regeneration establishment suggest that there is a shift away from less shade-tolerant species such as Douglas-fir, which is an important tree species for owl habitat (Table 1), and toward more shade-tolerant species such as western hemlock. Retained trees provide a seed source for enhancing natural regeneration establishment, but they influence the understorey growing environment by intercepting and reducing understorey light levels and competing with regeneration for soil moisture and nutrients. Retrospective field studies suggest that the retention of overstorey trees within densities prescribed by HVR/HWR reduces understorey Douglas-fir growth and thus has implications on the rate of stand growth in the future (Rose and Muir 1997; Acker et al. 1998; Zenner et al. 1998). Field research on the influence of overstorey retention on understorey growth and development is being conducted and will provide guidance on the implications of HVR/HWR prescriptions on long-term stand development.

However, regeneration dynamics can differ by retention pattern, and the HWR allowance for aggregation within the spacing practice may prove useful for addressing the stand conversion problem. The density of natural regeneration was 1.5–2.5 times greater in dispersed treatments than in the cleared areas between patches within aggregated treatments (Urgenson et al. 2013). At lower densities, dispersed retention promoted Douglas-fir, presumably by enhancing local seed rain within a relatively high light environment. At higher densities, dispersed retention favoured late-seral conifers, and thus enhanced survival of advanced regeneration and facilitated establishment and growth of shade-tolerant species. Furthermore, planting of early successional species, as recommended under HWR (Table 4), provides an early growth advantage over natural regeneration (e.g., hemlock) to ensure that the desired species composition is met at least in the early phase of stand development. HVR guidelines did not provide regeneration recommendations; monitoring of HVR outcomes should evaluate planting, stand tending, and harvesting practices in order to assess improvements gained through HWR.

The need to minimize wind damage to ensure the successful retention of large trees and recruitment of wildlife trees was identified subsequent to the implementation of the SOMP1 HVR, and is explicitly addressed in HWR. The SOMP1 HVR described suitable retention trees as large, live, healthy, and windfirm. In contrast, the best management practices and GWMs in the SOMP2 HWR contain specific recommendations for the windfirming of retained large trees (SOMIT 1997a; Spotted Owl Best Management Practices Working Group 2009; BCFLNR 2011, 2013). Under any type of retention system, some wind damage should be expected. An inventory of leave trees (species not identified) within the Cascade Range in Oregon that were

retained at densities comparable to those prescribed in HVR/HWR indicated that only 54% of the trees were alive 9–18 years after harvest (Busby et al. 2006). Most windthrow occurs soon after harvest[9] (Urgenson et al. 2013). In experimental trials, rates of wind damage due to stem breakage and uprooting in Douglas-fir stands of similar age and retention densities relative to those prescribed in HWR (15–40 trees/ha) range from 18% (Urgenson et al. 2013) to 25% (Smith and Beese 2012). D'Anjou[10] reported 33% wind damage to Douglas-fir at higher retention densities (63 and 105 trees/ha). Maguire et al. (2007) found higher mortality among dispersed trees (Douglas-fir and other species) than among aggregated trees, and higher mortality at lower retention levels. Retention pattern under HWR will, therefore, be important for mitigating potential higher rates of wind damage at the required retention levels (Table 4).

Typically, the damage rate among dispersed trees declines over time as the remaining trees develop windfirmness. That dominant trees have greater windfirmness than intermediate and suppressed trees supports the selection of dominant trees for retention, as directed under HWR[11] (Stathers et al. 1994). Managing the crowns of retention trees, such as by topping, is another way to control for wind damage (Rollerson et al. 2009). Windthrow assessment will be an important aspect of HVR and HWR monitoring. Retention tree densities are the same in both approaches, but the distribution requirements are slightly different (i.e., HWR is a true retention system), and HWR explicitly identifies windthrow as a concern that requires management attention.

3.2.2 Practice comparisons The evolution from the SOMP1 HVR to SOMP2 HWR is subtle for both retention pattern and structural retention objectives. There are, however, sufficient differences in pattern and implementation to suggest that potential differences in stand development and structural habitat outcomes will occur.

Harvest patterns

Both the SOMP1 HVR and SOMP2 HWR require uncut reserve patches in harvested stands, but each plan has slightly different approaches to accomplishing this due to changes in legislation between the times that SOMP1 and SOMP2 were implemented. SOMP1 recommended a minimum 10–15% range for reserve retention, using Wildlife Tree Patches and Riparian Reserve Zones (*Forest Practices Code of British Columbia* [BC MOF and BC MOE 1995b, 1995c]) to achieve this whenever possible, while SOMP2 requires a minimum 10% of the total area under prescription to be designated as untreated WTRA under the current *Forest and Range Practices Act* (Province of British Columbia 2004). Under SOMP2, the WTRA can exceed 10%, and retention must, at a minimum, meet any WTRA targets for landscape units and ecosystems with >10% requirement under the *Forest and Range Practices Act* (Spotted Owl Best Management Practices Working Group 2009). It is expected that the use of both HVR and HWR approaches will result in a minimum of 10% of the area under prescription being retained in reserves, but the potential to exceed this amount exists for both.

Both HVR and HWR recommend that reserves be located within the block (as opposed to along the edge of the opening) to better distribute the

9 Brian D'Anjou, unpublished data.
10 Ibid.
11 Ibid.

structural attributes of Spotted Owl habitat, but only HWR recommends employing a range of reserve sizes. The total area, and the sizes, shapes (e.g., linear versus not), and distribution of reserves in a harvest opening will have a significant influence on the recruitment of Spotted Owl habitat values as the stand regenerates, and as the surrounding landscape is developed.

Retention of a relatively even distribution of trees across the stand was recommended under HVR (SOMIT 1997a), but a wide range of patterns, including those lacking dispersion, was permissible (SOMIT 1999). In contrast, HWR specifies that no part of the area under prescription should be >40 m from the nearest retained tree; as such, HWR promotes a relatively disperse, uniform distribution of retention to provide for desirable owl habitat attributes throughout the stand, over time. However, due to safety issues on steep ground, the inter-tree distance using downhill cable logging systems may not be met, in which case alternative approaches will be proposed (BCFLNR 2011). HWR further requires that ≤40% of retained large trees be located within WTRAs or other reserves, and encourages retention of large single trees or small groups of trees across the harvested treatment area (Table 4). In theory, both approaches have the potential to distribute structural recruitment throughout the harvested area, but HWR has a higher probability of achieving this.

However, tree retention patterns (single trees and aggregates, and WTRAs) and tree densities will be highly variable, even with the HWR spacing and retention rules, because natural densities and distributions of the types of trees targeted for retention (i.e., those with the greatest current and future habitat value for Spotted Owls, including veterans, large trees, and wildlife trees) are highly variable. The leave-tree pattern following HVR and HWR will be affected by variations in ecosystem type, tree species, stand age, site conditions, safety considerations, and type of yarding system (ground-based versus cable).

Retention levels

Both HWR and HVR specify attribute retention by ecosystem type (i.e., wetter and drier) and provide retention targets and recommendations for the same core attributes associated with future owl habitat: large-diameter live trees, wildlife trees, and large downed wood. Both approaches also provide guidance for the tree species composition of retention and recruitment. While generally similar, there are some small differences between HVR and HWR that might have long-term implications for stand development and structural recruitment.

Large-tree and wildlife-tree density

The densities specified for retention of large trees under HWR remain consistent with those under HVR (Table 4), which are consistent with estimates from the Northwest Forest Plan (USDA and USDI 1994b). As noted earlier, determining retention densities to enhance the desired stand complexity for owl habitat, yet provide an environment for sustaining the desired Douglas-fir component, remains a research gap. Franklin (1992) suggested retaining 25–44 trees/ha to ensure an adequate supply of snags and woody debris, and 50–100 trees/ha would be required to create forests suitable for late-successional species. Zenner's (2000) retrospective assessment of Douglas-fir–dominated stands in Oregon revealed that retention of 40 trees/ha maximizes subsequent structural complexity while promoting shade-tolerant species without eliminating Douglas-fir species. The large-tree retention densities

prescribed for wet ecosystems under HVR/HWR (at least 15–30 of the largest trees per hectare) are below these estimates for developing late-successional structural characteristics, while the densities for dry ecosystems are more in line with current research (at least 40–80 of the largest trees per hectare). Although both HVR and HWR recommend that large leave trees be windfirm, as discussed earlier in this report, there is a high probability of some leave trees being lost in the immediate post-harvest years. HVR/HWR retention targets do not appear to be high enough to buffer any loss due to windthrow or other types of leave-tree mortality.

Retention of wildlife trees specified under HWR is less prescriptive than that specified under HVR. HVR required the retention of ≥ five large snags and/or dying trees > 76 cm dbh for wet ecosystems and > 51 cm dbh for dry ecosystems (SOMIT 1999; note that the Spotted Owl Management Inter-Agency Team 1997a recommended ≥ seven snags per hectare for dry ecosystems). Snags were to be retained in reserves, where possible, but outside the active falling area to address worker safety. SOMP1 went so far as to recommend snag creation; that is, the removal of low-value snags at the time of harvest and the creation of new "higher-value" snags after harvest through chemical, physical, or biological means (SOMIT 1999, Appendix A). Conversely, HWR recommends the less aggressive, strategic placement of WTRAs to protect high-value habitat attributes and to prevent dead trees from falling in order to keep the worksite safe. HWR does not specify snag retention targets (i.e., Wildlife Tree Classes 3–7/8), but it does recommend the inclusion of veteran trees and large dominant trees with defects (Wildlife Tree Classes 1 and 2; Appendix 1) in the retention density targets for large live trees in order to promote wildlife-tree recruitment over time. HVR, however, specified that trees retained to meet large-tree density targets must be alive and healthy (i.e., Wildlife Tree Class 1); live trees with defects (Wildlife Tree Class 2) were to be included in the ≥ five wildlife tree retention target. Whether any of these subtle differences in retention of large live and dead trees will result in any significant effects on structural outcome and habitat quality remains to be seen.

Tree species composition

Harvest with retention promotes retention of Douglas-fir and western redcedar trees (Spotted Owl Best Management Practices Working Group 2009). The climax forest in most of the ecosystems managed for owls is comprised primarily of these two tree species, which are among the longest lived. Dispersed veteran Douglas-fir trees are survivors of past disturbance, including fire, and are seed sources for natural regeneration. They provide a source of wildlife trees, and commonly provide nest structures for the Spotted Owl in British Columbia (Waterhouse et al. 2012). Redcedar tends to occur more predominantly in wetter ecosystems throughout the Spotted Owl's range. Redcedar is a more shade-tolerant species with a growth rate that is typically lower than that of Douglas-fir; therefore, it provides a long-term source of functional wildlife trees and can help develop a multi-storeyed forest structure, which is a stand structural attribute associated with owl habitat (Spotted Owl Best Management Practices Working Group 2009). Once dead and fallen, the slow decay rate of Douglas-fir and redcedar (Huggard and Kremsater 2007) provides long-term enhancement of the structural complexity of the forest floor that is necessary to support Spotted Owl prey species.

Heavy volume removal also recommends the retention of veteran Douglas-fir, concentrated in reserve areas, as well as grand fir, which is similar to Douglas-fir and is retained as a replacement for Douglas-fir on drier sites within some stands (SOMIT 1997a). The HVR recommendations focus overall on compositional and structural diversity for retention, and specify that reserve areas should be multi-species, multi-aged, and multi-layered. The maintenance of two or three conifer species in areas of post-harvest tree retention was recommended. However, hemlock retention potentially causes two undesired consequences. First, hemlock retention may provide seed to increase hemlock regeneration density, which is undesirable in maintaining Douglas-fir–dominated regeneration. Secondly, if infected with mistletoe, hemlock retention may infect the regenerating hemlock, which would affect the incorporation of this species into stands.

Retention of a deciduous component (6–10 trees/ha), within or outside of reserves, and interspersed with conifer retention, was recommended by HVR for vegetation and structural diversity. HWR does not preclude retention of deciduous trees, though it is not specifically addressed or encouraged. Superior owl habitat may contain only a small component of deciduous trees (Table 1). Although not specified, "small component" would likely refer to aggregates or single, larger deciduous trees that are associated with riparian features or a natural gap, and which may have wildlife tree value. The shorter life span of deciduous trees—including red alder (*Alnus rubra*) up to 100 years old or bigleaf maple and black cottonwood (*Acer macrophyllum*) and *Populus trichocarpa* up to 200 years old—makes them less desirable candidates than conifers when recruiting long-term owl habitat (e.g., 250 years plus). Deciduous tree leaf fall results in a decline in overstorey deciduous canopy cover, which may reduce prey security. But deciduous trees can recruit heart rot cavities sooner than conifers, which can be used as dens (e.g., flying squirrel use of alder [Carey 1995]) or as nests (e.g., Spotted Owl use of cottonwood [Waterhouse et al. 2012]). Both HVR and HWR allow for the retention of a minor component of large deciduous trees, if present.

Large downed wood

Heavy volume removal guidelines for the retention of large CWD were the same as those for LVR. All existing pre-harvest CWD was to be left on site, and an additional small amount of post-harvest large CWD was to be recruited (with volume and size classes specific to wet or dry ecosystem type) (Table 4). Together, these pre- and post-harvest volumes are expected to yield "large" CWD volumes approaching those specified for superior owl habitat (Table 1).

Similar to HEPS under SOMP2, HWR focusses on the retention of pre-harvest large CWD, which is not assessed as waste according to the criteria in the current *Provincial Logging Residue and Waste Measurement Procedures Manual* (BC MOF 2005). Unlike HEPS, HWR sets a minimum specified volume of large CWD (75 m^3/ha for all ecosystem types), which can be met by pre-harvest large CWD and/or post-harvest, non-merchantable, large CWD if the minimum target is not met by the pre-harvest volume available in a stand (BCFLNR 2011, 2013). However, post-harvest CWD is subject to waste assessment.

The minimum volume of large CWD required for superior owl habitat in dry ecosystems is 75 m^3/ha, which is consistent with the HWR minimum

specified volume. However, the HWR minimum specified volume is substantially less than the 250 m³/ha required for superior owl habitat in wet ecosystems (Table 1). This discrepancy between the minimum retention volume and superior habitat conditions in wet ecosystems is large, and monitoring is required to evaluate whether the minimum retention volume meets HWR objectives. HWR is not intended to create superior owl habitat immediately, as do HEPs, but to accelerate the development of superior conditions more quickly than in a typical clearcut treatment. Retention of existing large CWD under HWR is intended to provide structural complexity to the forest floor during the early phase of stand development, while large-tree retention provides a recruitment source for future CWD; both actions should accelerate development of superior quality habitat. Furthermore, HWR focusses on retention of large pieces of redcedar (Table 4) because of its slow decay rate (Huggard and Kremsater 2007). Large downed redcedar will persist long after harvesting operations have been completed and will contribute structural habitat as the stand develops into Spotted Owl habitat. As noted earlier, redcedar takes longer to grow than other conifer species, and is long-lived, so the recruitment rate of fallen redcedar into the downed wood pool is quite low, which makes retention of existing pre-harvest downed redcedar a priority.

Consistent with the Chief Forester's direction given in May 2010 (BCFLNR 2010), both HVR and HWR recommend that large CWD be distributed across the treatment area and not piled and burned at the roadside or landing, where it has little ecological value. The retention system used in HWR should further ensure the spatial distribution of future large CWD throughout the treatment area outside of WTRAs.

As previously discussed for HEPs, large CWD is defined in the SOMP2 GWMs for the current Wildlife Habitat Area Orders as fallen trees or logs with the top-end diameter >7.5 cm. This definition does not match the definition of large CWD for superior owl habitat (Table 1), the diameter limits of large CWD specified in SOMP1 (Tables 2 and 4), or the definition of large CWD in the SOMP2 HEPs best management practices (Table 2) or current government policy (BCFLNR 2010). However, the best management practices and GWMs for HWR do specify that large CWD retention should be representative of pre-harvest species and sizes, and the appendices of the WHA Orders note that the intent of the GWMs is to retain a high component of fallen trees and logs >5 m long, with a minimum diameter of 50 cm in dry zones and 75 cm in wet zones (BCFLNR 2011, 2013). Also, the HWR best management practices suggest that the breaking of long, large pieces (>10 m long and >20 cm diameter) be avoided during harvesting operations (Spotted Owl Best Management Practices Working Group 2009).

Although the definition of large CWD under the SOMP2 GWMs includes stumps, any fresh-cut stumps created during HWR are not intended to contribute large downed wood unless no other type of large CWD is available (Appendix 1) (BCFLNR 2011, 2013), which is highly unlikely given the average pre- and post-harvest volumes of CWD in ecosystems that support Spotted Owls (Densmore 2011). As noted earlier for SOMP2 HEPs, monitoring of CWD management outcomes will be important for determining if the objectives of SOMP2 are met by the current definition of large CWD in the GWMs in the WHA Orders.

Although not explicitly addressed for the SOMP1 HVR, the challenge in achieving retention of large CWD under SOMP2—or in meeting any non-timber objective in general—is that retention of any post-harvest, non-mer-

chantable wood for owl habitat must consider and incorporate other management constraints such as residue and waste, and risks for wildfire, insect pests, and disease (Spotted Owl Best Management Practices Working Group 2009; BCFLNR 2011, 2013).

3.2.3 Summary of heavy volume removal and harvest with retention comparison The differences between the SOMP2 HWR and SOMP1 HVR that are anticipated to influence stand development and habitat quality outcomes are summarized in Table 5. Conducting monitoring to assess the structural and biological outcomes of what appear, for the most part, to be relatively minor differences, will be important for evaluating the success of both sets of practices in accelerating structural development, and for determining any potential improvements associated with SOMP2. The main advancement of HWR over HVR was to establish the formal practice that no point within the block is more than a tree length (40 m) from a retained tree (Table 4), and as such HWR provides clear direction on the expected pattern of distribution, while providing flexibility to aggregate trees. Practices under HWR also establish the role of retention of veteran and live dominant trees with defects for longer-term recruitment of structural attributes of superior owl habitat. However, the high degree of variability in possible retention patterns under the two approaches may make comparative assessment difficult, and will require a standardized classification to characterize post-harvest retention.

Some practices did not survive the transition from HVR to HWR. Branch retention (within 3 m of ground) was specified under HVR but not HWR, given that branch retention will be otherwise achieved through stand-density management. HVR explicitly recommended maintaining or developing at least three canopy layers, but this is addressed in HWR by the requirement for well-distributed structural retention in the regenerating stand.

4 A REVIEW OF SOMP1 AND SOMP2 IMPLEMENTATION

As a first step in developing a monitoring and evaluation framework for the two SOMPs, we reviewed the implementation of SOMP1 and SOMP2 from 1997 to 2011 to assess the current level of harvesting under each strategy, and to characterize the types of spatial patterns of removal and retention that have resulted. SOMP1 openings were designed in 1996 and implementation end dates ranged from 1997 to 2010; under SOMP2, designing started in 2009, and implementation end dates range from 2010 to 2011 in this study (BCFLNR 2011, 2013). The use of practices under SOMP1 and SOMP2 is anticipated to result in differences in harvest and retention patterns and in levels of retention, as discussed in Section 3. The high degree of variability in retention pattern is possible under SOMP1 and SOMP2 approaches due to the natural variability in forest ecosystems; therefore, a standardized approach to characterizing post-harvest spatial patterns is required to facilitate comparative assessment.

We determined the scope of harvesting completed under both SOMPs and conducted a preliminary assessment of implementation:

1. Data compilation. We identified openings designed under SOMP1 and SOMP2, and compiled all available information on each opening. An opening refers to the area under prescription to which a cutting permit applies.

TABLE 5 *Summary of similarities and differences between harvest with retention (HWR) and heavy volume removal (HVR) that are anticipated to affect stand development and Spotted Owl habitat quality outcomes (SOMP = Spotted Owl Management Plan)*

Guideline and practice	HWR (SOMP2)	HVR (SOMP1)
Forest management approach		
Silviculture systems	Retention	Clearcut with reserves and single/group leave-tree retention[a]
Reserves	Minimum 10% of total area under prescription	Minimum 10% of total area under prescription
	Forest and Range Practices Act—Wildlife Tree Retention Areas (WTRAs)	*Forest Practices Code*—Wildlife Tree Patches/Riparian Reserve Zones
	No harvesting in reserves	Light volume removal harvesting allowed in reserves to improve habitat quality
Planting direction	Yes	No
Practice		
Harvest pattern		
Reserve distribution	Reserves inside the block and contiguous with block edges	Reserves inside the block and contiguous with block edges
Retention distribution	Retention inside reserves and throughout the treatment area	Retention inside reserves and throughout the treatment area
	Maximum of 40% large-tree retention within WTRAs and other reserves	Up to 100% of retention may be located within uncut patches and riparian reserves
	Maximum inter-tree distance	Relatively even distribution of stems recommended
	Total area under prescription-wide average	
Retention level		
Density of large trees	Wet: minimum average of 15 of the largest 30/ha	Wet: average of 15 of the largest 30/ha
	Dry: minimum average of 40 of the largest 80/ha	Dry: average of 40 of the largest 80/ha
	Live, healthy, or with defects	Live, healthy
Density of wildlife trees	WTRAs	Retention of large snags and/or dying trees
		Snag creation
Tree species composition of retention	Douglas-fir and redcedar	Douglas-fir and grand fir
		Two to three conifer species
		6–10/ha deciduous
Large downed wood	Minimum 75 m^3/ha of coarse woody debris (CWD)	All pre-harvest retention
	Pre-harvest redcedar CWD retention up to a minimum of 25 m^3/ha, if present	Wet and dry retention targets for non-merchantable, post-harvest, large CWD
	Post-harvest, non-merchantable retention if required to meet minimum	
	Retention of large pieces recommended	

a The definition of a single/group leave tree retention system: (a) retain individual trees or groups of trees to maintain structural diversity over the area of the cutblock for at least one rotation, and (b) leave more than half the total area of the cutblock within one tree height from the base of a tree or group of trees, whether or not the tree or group of trees is inside the cutblock (BC MOF 2003). A clearcut with reserve system is a variation of clearcutting that retains uniformly spaced or small groups of trees for purposes other than regeneration (de Montigny and Nigh 2009).

2. Pattern classification. We developed a standardized approach to classifying the spatial patterns of harvest and retention that resulted from SOMP1 and SOMP2 practices (i.e., pattern classification). This was achieved by evaluating maps and imagery, and conducting a field review of a subsample of openings. Stand development and ecological succession can differ between types of harvest and retention patterns and thus produce Spotted Owl habitat of varying quality.
3. Treatment summaries. We summarized the amount of area treated under SOMP1 (i.e., LVR/HVR) and SOMP2 (i.e., HEP/HWR) harvesting practices by district, ecosystem type, pattern classification, and forest age, if available.

4.1 Database of Harvest Openings

The Spotted Owl Management Plan 1 openings harvested from 1997 to 2005 were initially identified by overlaying satellite imagery (obtained in 2005/06 via IKONOS 5) with the SOMP1 Special Resource Management Zones, and by cross-referencing with 1:20 000 forest cover maps (MapView). SOMP1 openings harvested between 2006 and 2010, and SOMP2 openings harvested in 2010 and 2011, were identified using RESULTS[13] and consultation with licensees and the districts. Opening-specific information was obtained from RESULTS and pre-harvest silvicultural prescriptions (Province of British Columbia 1993), silvicultural plans (Province of British Columbia 1996), and site plans (Province of British Columbia 2004).

For each identified opening, information derived from RESULTS, the districts, the licensees (see above), and aerial images dated closest to the completion of harvest (including Google Earth[14] images) were used to derive a set of opening attributes (Table 6).

TABLE 6 *Harvesting and silvicultural attributes derived for SOMP openings and sub-openings[a]: 1997–2011*

Attribute	Detail
Management plan	SOMP1, SOMP2
Natural Resource District	Chilliwack or Sea to Sky
Ecosystem type	Wetter, drier
Harvesting practice	Light volume removal / habitat enhancement practices; heavy volume removal / harvest with retention
Stand age at harvest	Available for some openings
Pattern class (harvest or retention)	Derived from implementation review
Total area under prescription	Includes harvested area and reserves (Wildlife Tree Patches, Wildlife Tree Retention Areas, and riparian reserves)
Net area to be reforested	Excludes reserves
Yarding system	Ground-based, cable, helicopter

a Openings with more than one pattern class were sub-divided into sub-openings, each with a unique pattern class, for which a complete list of opening attributes was compiled.

13 RESULTS (Reporting Silviculture Updates and Land Status Tracking System) tracks and reports on spatial and business data for harvest openings; data are entered 1 year after completion of harvesting. The database is maintained by the British Columbia Ministry of Forests, Lands and Natural Resource Operations and DataBC (www.data.gov.bc.ca). RESULTS was not created until 2004.

14 Google Inc. (2012). Google Earth.

Openings for which information was missing were placed in the "Unclassified" pattern class. Openings that lacked internal treed retention were placed in the "Clearcut" pattern class. Wildlife tree retention (i.e., Wildlife Tree Patches for SOMP1) tended to be poorly documented, particularly when located outside the harvested area, along block boundaries.

4.2 Pattern Classification

As described in Section 3, harvest and retention patterns are anticipated to have a significant effect on the maintenance and recruitment of Spotted Owl superior quality habitat. We developed a pattern classification to describe the configuration of harvest removal for selection systems (i.e., LVR/HVR, harvest pattern) and the configuration of green-tree retention systems (i.e., HVR/HWR, retention pattern). Pattern classes were developed following field reviews of openings conducted in the Chilliwack Natural Resource District during 2005, 2008, and 2011, and in the Sea to Sky Natural Resource District during 2008, and from a review of relevant literature and post-harvest Google Earth imagery (BC MOF and BC MOE 1995a; Franklin et al. 1997; D'Anjou et al. 2006; BC MOFR 2008). Most of the harvesting available for field review was implemented under SOMP1. In the brief period of our review (2009–2011), only a few openings had been implemented under the SOMP2 HWR, and no HEPs harvesting had been conducted. Pattern classes for openings were determined from tree retention or removal patterns that were visible in the field and/or on images, or as described by documentation (silviculture plans, pre-harvest silviculture plans). Openings of the same pattern may include varying amounts of structures that are considered vital for owl habitat (i.e., large live trees, wildlife trees, large downed wood), which will be evaluated at some point in the future. Pattern classes will be used to categorize openings to facilitate future monitoring and evaluation of retention levels and the future habitat quality of the resulting stands.

4.2.1 Harvest pattern classes For LVR, seven harvest pattern classes were identified during the review (Figure 2). The range in harvest pattern classes is the result of several factors, including the individual forester's interpretation of site-specific site conditions, the management objectives, and the availability of logging contractors and equipment. Harvest classes represent a combination of traditional silvicultural system patterns (single-tree selection, group selection) or thinning and yarding system (ground-based, cable-yarding, helicopter) (Figure 2).

The resulting harvest pattern was strongly linked to yarding method (Table 7). For example, canopy gaps tended to be yarded by helicopter, and trees were removed singly or in groups. Lifting trees above the stand tends to minimize damage to the adjacent trees and understorey trees and shrubs compared with cable yarding. Cable yarding tends to create straight corridors and can damage desirable remnant stand structure (smaller trees and shrubs), and it reduces operational flexibility to meet worker safety requirements. Ground-based harvesting can add pattern complexity to access corridors through the addition of branched, secondary corridors (observed in the field). Thinning applied under SOMP1 was exclusively ground based (Figure 2).

As noted in Section 3, the predominant LVR harvest pattern, either by ground-based yarding or cable yarding, is the corridor. So far, only helicopter yarding has mimicked "natural" canopy gaps using single-tree and group selection systems. The "natural" canopy gap required under HEPs (≤0.03 ha

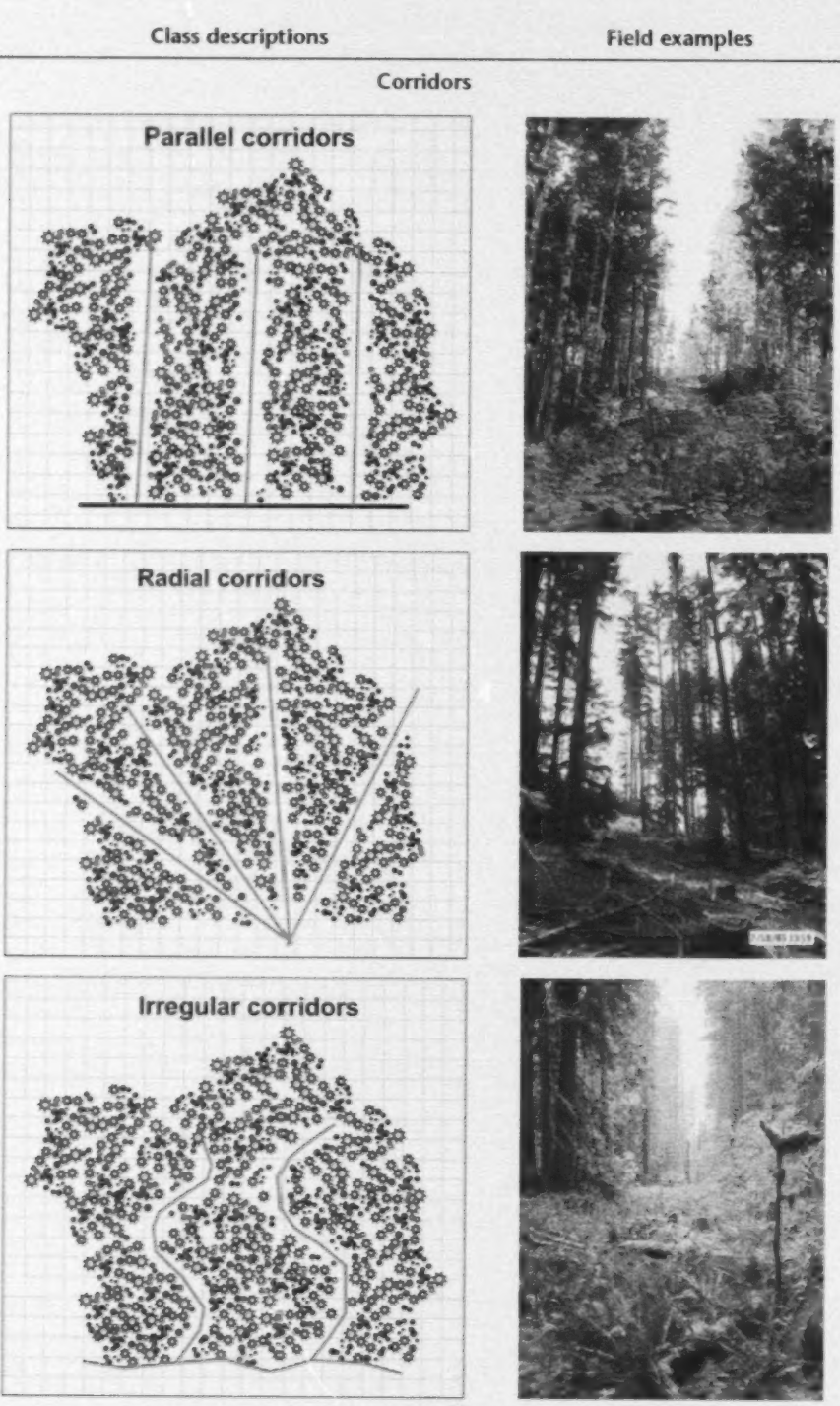
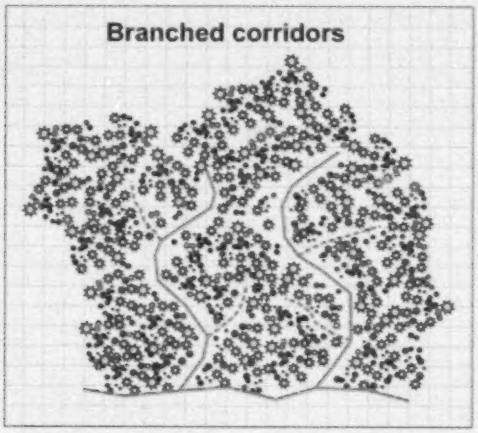
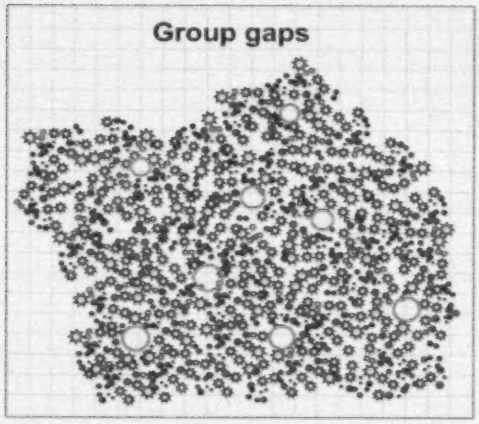
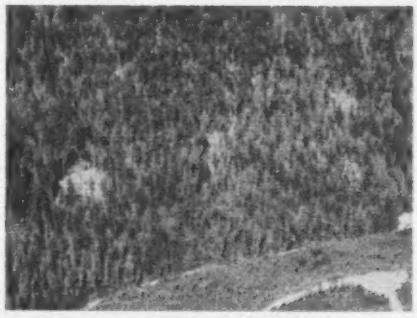


FIGURE 2 *Harvest pattern classes for monitoring light volume removal (Spotted Owl Management Plan 1) and habitat enhancement practices (Spotted Owl Management Plan 2). Habitat enhancement practices had not been implemented at the time of this review. Harvest pattern classes were based on a review of light volume removal openings; habitat enhancement practices were anticipated to use similar harvest methods and potentially produce combinations of similar patterns.*



Canopy gaps





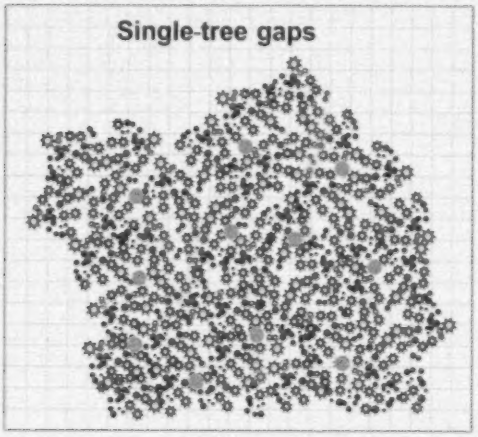


FIGURE 2 *Continued.*

Thinning

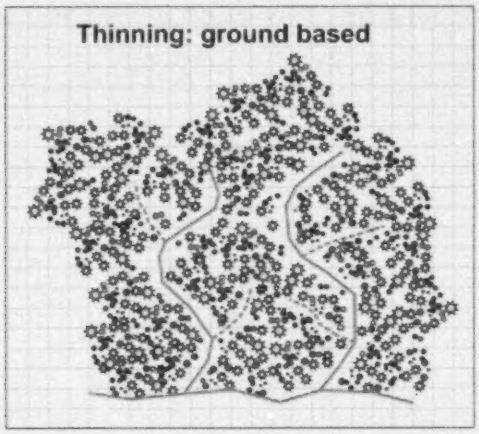


FIGURE 2 *Concluded.*

[300 m²]) is intended to approximate a natural "treefall gap"; that is, small openings (generally < 0.1 ha [1000 m²]) in the forest created by the death of one or more trees (Schliemann and Bockheim 2011). The continued application of HEPs under SOMP2 will likely create more gap pattern classes by implementing a creative combination of silvicultural and yarding systems.

Differences in post-harvest stand development and quality of owl habitat between harvest pattern classes are expected. For example, light levels that reach the understorey will differ between radial corridors oriented over a broad range of directions and parallel-oriented corridors (Figure 2). The creation of more complex removal patterns, such as the branched corridor pattern produced by ground-based yarding, should result in more broadly distributed light penetration and enhanced spacing for owl movement than a simpler set of dispersed individual corridors produced by the same yarding method (e.g., irregular corridors) (Figure 2). Different harvest patterns will also directly affect the retention of other important habitat attributes, such as shrubs and downed wood, wildlife trees (which may need to be felled as danger trees), or large residual trees that may be damaged during yarding.

TABLE 7 *Harvest patterns resulting from the implementation of light volume removal silvicultural systems and thinning using three main yarding systems: 1997–2011. (See Figure 2 for relevant diagrams and photographs.)*

	Silvicultural system		
Yarding system	**Single-tree selection**	**Group selection**	**Thinning[a]**
Ground-based	N/A	Irregular corridors Branched corridors	Thinning
Cable	N/A	Parallel corridors Radial corridors	Thinning
Helicopter	Single-tree canopy gaps	Group canopy gaps	N/A

a Applied only to young stands (30–80 years old).

Monitoring of stand development and owl habitat may result in further grouping or splitting of harvest pattern classes depending on whether they create different habitat outcomes.

4.2.2 Retention pattern classes Five retention pattern classes were identified from a review of HVR and HWR openings and sub-openings implemented from 1997 to 2011 (Figure 3). Clearcut with no observable retention or reserves was also observed. Although this system does not meet the intent of HVR, we included it as part of the review on implementation but did not include it as a retention class. Terms and definitions used to classify the HVR/HWR patterns observed in this study are as follows:

- dispersed retention: trees retained individually and/or in a collection (≤ five); more frequently applied under the retention system of HWR (Section 3);

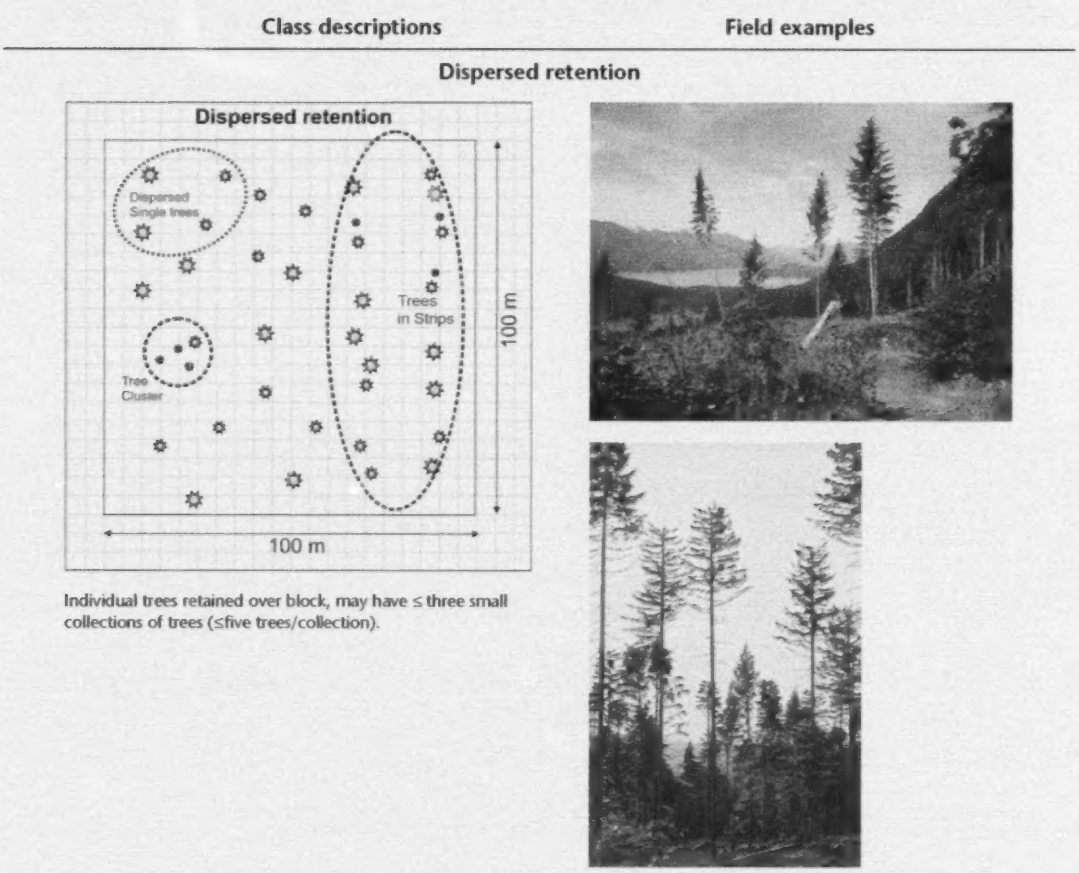
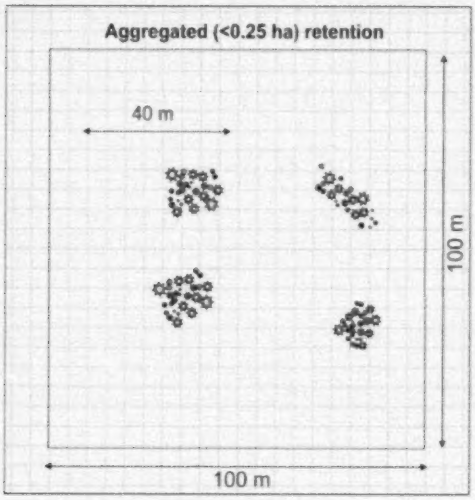


FIGURE 3 *Retention pattern classes for monitoring heavy volume removal (clearcut with reserve, Spotted Owl Management Plan 1) and harvest with retention (retention system, Spotted Owl Management Plan 2). Class descriptions and top-down diagrams are provided with ground-level photographic examples for each.*

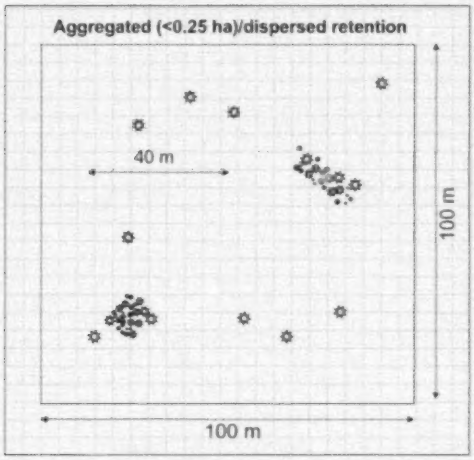
Aggregated retention



Tree retention in aggregations, <0.25 ha; can include retention in strips, including riparian reserves.

FIGURE 3 *Continued.*

Aggregated/dispersed retention

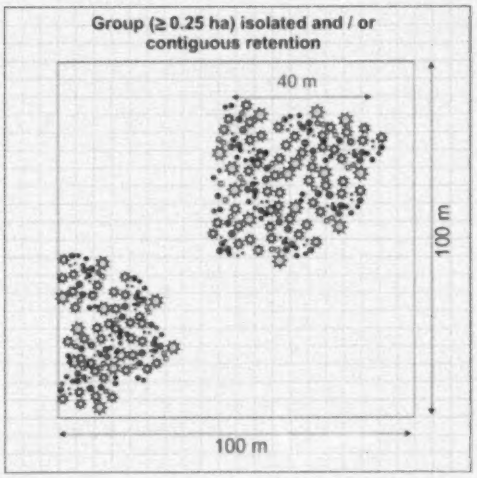


Combination of aggregated and dispersed retention in the block.

FIGURE 3 *Continued.*

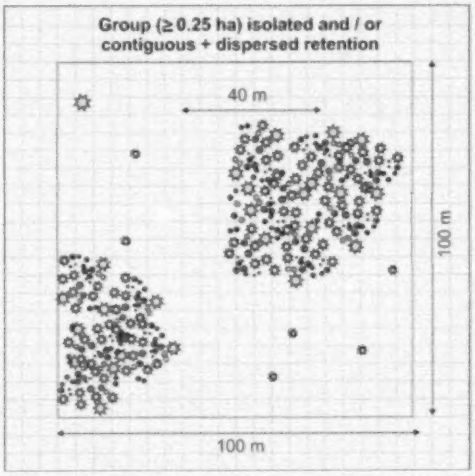
Class descriptions	Field examples

Group retention



Isolated groups of trees, ≥0.25 ha; will include reserves (e.g., Wildlife Tree Retention Areas, Wildlife Tree Patches, Riparian Reserve Zones).

Group/dispersed retention



Contiguous with block edge and/or isolated groups of trees and single trees, dispersed throughout the block.

FIGURE 3 *Concluded.*

- aggregated retention: trees retained in aggregates < 0.25 ha, either in clusters or strips; and
- group retention: retention of intact groups of trees ≥ 0.25 ha; most often set aside as legislative reserves (i.e., Wildlife Tree Patch, Riparian Reserve Zone, Wildlife Tree Retention Area). Groups may be isolated from surrounding intact forest or may be contiguous with the forested block boundary. Riparian reserves may act as group retention.

Retention patterns include the three primary retention patterns described above, plus two pattern classes that combine primary retention patterns: aggregated/dispersed and group/dispersed. Other retention patterns and combinations will be possible under SOMP2 (e.g., aggregated/group).

While yarding system is not incorporated into the retention pattern classification, different yarding systems can create different ground disturbances and have varying impacts on existing advanced regeneration and understorey vegetation, including regeneration and establishment (as discussed for the harvest pattern classification) (Franklin and Kohm 1997; D'Anjou 1998, 2002). For monitoring, the classification system can be refined to include yarding divisions (classes) to determine whether that variation in yarding produces different outcomes for stand development and owl habitat quality.

The retention pattern classification developed here has similarities to other systems developed for describing retention levels and patterns (Beese 2009; Rollerson et al. 2009). As noted earlier, assessing harvest patterns is only part of the first step in evaluating the implementation and effectiveness of SOMP guidelines and practices. Monitoring of actual green-tree and wildlife-tree retention levels for HVR and HWR, along with other key attributes of superior owl habitat, will require attribute- and block-specific field sampling protocols in order to document any deviation from prescribed and recommended retention levels (implementation), and to evaluate stand development and habitat quality outcomes in the regenerating stand.

4.3 Summary of SOMP1 and SOMP2 Implementation

Our database of harvesting activities under SOMP from 1997 to 2011 (Table 8) included 131 SOMP1 openings (comprising 142 sub-openings) and seven SOMP2 openings (no sub-openings determined therefore equal to 7 sub-openings).

Overall, HVR represented most of the harvesting implemented under SOMP1 (73% of the total area under prescription) (Table 8); under SOMP2, only HWR has been applied (100% of the total area under prescription) (Table 8). HVR was implemented equally across both districts; LVR was focussed in the Chilliwack Natural Resource District (93% of the total area under prescription) (Table 8). Although the reasons for the low use of LVR in the Sea to Sky Natural Resource District are unknown, factors that may have limited its application, and may continue to influence HEP implementation, include limited availability of stands suited for enhancement prescriptions (due to age, topography, tree species, and stand density), access issues, and operability constraints.

The SOMP1 LVR and HVR sub-openings were substantially larger in the Chilliwack Natural Resource District than in the Sea to Sky Natural Resource District (based on net area to be reforested [NAR]) (Table 8). However, while the total area under SOMP1 prescription in the Chilliwack Natural Resource District was much larger than that in the Sea to Sky Natural Resource District (Table 8), the proportion of NAR was, on average, the same in the Chilliwack

TABLE 8 *Summary of harvesting under the SOMP1 light volume removal (LVR) and heavy volume removal (HVR), and the SOMP2 harvest with retention (HWR) in the Chilliwack and Sea to Sky Natural Resource Districts: 1997–2011*

		SOMP1 1997–2010			SOMP2 2009–2011
Harvesting attribute	**District[a]**	**LVR**	**HVR**	**Total**	**HWR**
Sub-openings[b] (no.)	Chilliwack	31	50	81	7
	Sea to Sky	6	55	61	0
	Total	37	105	142	7
Total area under prescription (TAUP)[c] (ha)	Chilliwack	725.2	1250.9	1976.1	228.5
	Sea to Sky	55.5	885.8	941.3	0.0
	Total	780.7	2136.7	2917.4	228.5
Total net area to be reforested (NAR)[c] (ha)	Chilliwack	609.5	819.5	1429.0	178.4
	Sea to Sky	41.3	591.2	632.5	0.0
	Total	650.8	1410.7	2061.5	179.4
Average TAUP for sub-openings[c] (ha)	Chilliwack	30.2 (SD 30.2)	27.2 (SD 18.4)	28.2 (SD 23.0)	32.6 (SD 31.0)
	Sea to Sky	9.3 (SD 12.9)	16.7 (SD 16.2)	16.0 (SD16.0)	0.0 (SD 0.0)
	Average	26.0 (SD 28.7)	21.6 (SD 18.0)	22.6 (SD 20.9)	32.6 (SD 31.0)
Average sub-opening area in NAR[c] (ha)	Chilliwack	20.3 (SD 25.7)	16.7 (SD 12.1)	18.1 (SD 18.6)	25.6 (SD 25.3)
	Sea to Sky	6.9 (SD 10.5)	10.7 (SD 11.0)	10.4 (SD 10.9)	0.0 (SD 0.0)
	Average	18.1 (SD 24.2)	13.6 (SD 11.8)	14.7 (SD.0)	25.6 (SD 25.3)

a The Sea to Sky Natural Resource District was formerly called the Squamish Forest District.

b In total, 131 openings (72 in the Chilliwack Natural Resource District and 59 in the Sea to Sky Natural Resource District) were created under SOMP1. These were subdivided into a total of 142 sub-openings. Seven openings (five in the Chilliwack Natural Resource District and two in the Sea to Sky Natural Resource District) incorporated two harvesting approaches (LVR and HVR), which resulted in 14 sub-openings. Both HVR and LVR were applied in one opening in the Chilliwack Natural Resource District, and two harvest pattern classes were used in the LVR sub-opening, which resulted in three sub-openings for the one opening. Two LVR openings (Chilliwack Natural Resource District) had two harvest pattern classes, which produced four sub-openings.

c Two sub-openings, one LVR and one HVR, in the Chilliwack Natural Resource District were not included in areal summaries due to missing data on TAUP and NAR.

Natural Resource District (72%) and Sea to Sky Natural Resource District (67%), which indicates relatively equivalent levels of retention. As noted during database compilation, data on wildlife tree retention area were unavailable for this review. The Chilliwack Natural Resource District brought more area under prescription compared to the Sea to Sky Natural Resource District under SOMP1, and the larger opening sizes were potentially related to several factors, including district harvest levels, forest attributes (larger stands suited for a single prescription), and access issues.

The few sub-openings harvested under HWR have greater NAR than the largest sub-openings created for SOMP1 (LVR or HVR) (Table 8), which may be a reflection of topography, but HWR represents a true retention system that widely distributes green-tree retention across the NAR. Overall, sub-opening size varied considerably within and among districts and harvest approaches (Table 8), and it is likely under the SOMP2 HEPs that this variation will continue, given the large number of factors that affect development of prescriptions.

Most LVR sub-openings (95% classified and unclassified) (Table 9) and HVR sub-openings (80% classified and unclassified) (Table 10) were implemented in the drier ecotype. SOMP1 harvesting focussed more on the drier

TABLE 9 *Summary of sub-openings and total net area to be reforested (NAR) for light volume removal (LVR) (n = 37), by district, ecosystem, and harvest pattern class*

				Harvest pattern class						
				Corridors				Gaps		
Harvesting attribute	District[a]	Ecosystem	Un-classified[b]	Parallel or radial	Irregular	Branched	Thinning	Groups	Single tree	Total classified
Sub-openings (no.)	Chilliwack	Drier	9	1	6	2	2	9	1	21
		Wetter	0	0	0	0	1	0	0	1
	Sea to Sky	Drier	5	0	0	0	0	0	0	0
		Wetter	0	0	0	0	0	1	0	1
	Total	Total	14	1	6	2	3	10	1	23
NAR (ha)	Chilliwack	Drier	179.9	5.2	88.0	15.8[c]	34.8	181.3	23.8	348.9
		Wetter	0.0	0.0	0.0	0.0	80.7	0.0	0.0	80.7
	Sea to Sky	Drier	40.8	0.0	0.0	0.0	0.0	0.0	0.0	0
		Wetter	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.5
	Total	Total	220.7	5.2	88.0	15.8	115.5	181.8	23.8	430.1

a The Sea to Sky Natural Resource District was formerly called the Squamish Forest District.

b Unclassified sub-openings had insufficient information available to assign a harvest pattern class.

c One sub-opening in the Chilliwack Natural Resource District with a branched or secondary corridor pattern created by ground-based yarding was excluded because the NAR for it was not reported.

TABLE 10 *Summary of sub-openings and total net area to be reforested (NAR) for heavy volume removal (HVR) (n = 105), by district, ecosystem, and retention pattern class*

				Retention pattern class						
Harvesting attribute	District[a]	Ecosystem	Un-classified[b]	Aggregated retention	Dispersed retention	Aggregated dispersed retention	Group retention	Group dispersed retention	Clearcut	Total classified
Sub-openings (no.)	Chilliwack	Drier	11	2	2	7	4	13	4	32
		Wetter	1	0	0	5	0	1	0	6
	Sea to Sky	Drier	1	0	8	16	4	11	1	40
		Wetter	8	2	4	0	0	0	0	6
	Total	Total	21	4	14	28	8	25	5	84
NAR (ha)	Chilliwack	Drier	158.3	44.5	32.0[c]	95.9	67.7	177.1	63.1	480.3
		Wetter	40.0	0.0	0.0	105.6	0.0	35.3	0.0	140.9
	Sea to Sky	Drier	14.4	0.0	134.4	175.1	57.6	119.5	0.6	487.2
		Wetter	16.2	5.3	68.1	0.0	0.0	0.0	0.0	73.4
	Total	Total	228.9	49.8	234.5	376.6	125.3	331.9	63.7	1181.8

a The Sea to Sky Natural Resource District was formerly called the Squamish Forest District.

b Unclassified sub-openings had insufficient information available to assign a harvest pattern class.

c One HVR sub-opening in the Chilliwack Natural Resource District was excluded because the NAR for it was not reported.

ecosystem than on the wetter one, possibly due to operability, access, and jurisdiction (e.g., parks) issues, and/or wood values. It is unknown if SOMP2 HEPs will be similarly under-implemented in the wetter ecosystems; however, most of the HWR sub-openings (71% classified and unclassified) (Table 11) have been in wetter ecosystems.

We classified only 66% (by NAR) of the LVR sub-openings (Table 9); the remainder lacked adequate documentation for classification. All classified LVR harvesting occurred in the Chilliwack Natural Resource District; LVR in the Sea to Sky Natural Resource District totalled only 41.3 ha of NAR, of which only 0.5 ha could be classified. Classified sub-openings represented a mixture of LVR harvest pattern classes (Table 9), dominated by:

- helicopter yarding for creating canopy gaps, which was conducted on 48% of classified NAR (stands >80 years old, mostly group selection);
- ground-based yarding for thinnings, which was conducted on 27% of classified NAR (two stands 40–60 years old and one stand 141–250 years old); and
- ground-based yarding to create irregular corridors, which was conducted on 24% of classified NAR (stands >120 years old).

Group and single-tree selection will likely continue under HEPs, but, as discussed in Section 3, there should be a shift away from corridor patterns. More than half of the LVR harvesting produced corridor or block-wide thinning patterns (52%) (Table 9). Though not explicitly addressed, thinning is possible under HEPs, and there is sound scientific support for its continued use.

Overall, LVR was, as expected, concentrated in mature forest stands for those openings with reported age (age class at harvest: 41–60 years [14%]; 81–140 years [69%]; 250+ years [17%]; $n = 29$ sub-openings). The variety of harvest patterns observed for LVR reflect, in part, the influence of stand age, in combination with habitat condition, other site-specific factors, and deci-

TABLE 11 *Summary of sub-openings and total net area to be reforested (NAR) for harvest with retention (HWR) (n = 7), by district, ecosystem, and retention pattern class*

				Retention pattern class					
Harvesting attribute	District[a]	Ecosystem	Unclassified[b]	Aggregated retention	Dispersed retention	Aggregated dispersed retention	Group retention	Group dispersed retention	Total classified
Sub-openings (no.)	Chilliwack	Drier	0	0	0	2	0	0	2
		Wetter	5	0	0	0	0	0	0
	Sea to Sky	Drier	0	0	0	0	0	0	0
		Wetter	0	0	0	0	0	0	0
	Total	Total	5	0	0	0	0	0	2
NAR (ha)	Chilliwack	Drier	0.0	0.0	0.0	90.9	0.0	0.0	90.9
		Wetter	110.0	0.0	0.0	0.0	0.0	0.0	0
	Sea to Sky	Drier	0.0	0.0	0.0	0.0	0.0	0.0	0
		Wetter	0.0	0.0	0.0	0.0	0.0	0.0	0
	Total	Total	110.0	0.0	0.0	90.9	0.0	0.0	90.9

a The Sea to Sky Natural Resource District was formerly called the Squamish Forest District.
b Unclassified sub-openings had insufficient information available to assign a harvest pattern class.

sions made by individual foresters. Therefore, given the targeting of 60- to 140-year-old stands for enhancement, future HEPs prescriptions will continue to be similarly designed. However, the shift in practices may result in novel harvest patterns that have not yet been produced in SOMP application.

There was sufficient documentation to classify most of the SOMP1 HVR sub-openings by retention pattern (80%) (Table 10). Dispersed retention, alone or in combination with aggregated or group retention, was the most common retention pattern applied between 1997 and 2011 (Table 10). As noted earlier, HVR represented most of the harvesting under SOMP1, and was applied relatively evenly across the two districts (50 sub-openings in the Chilliwack Natural Resource District versus 55 in the Sea to Sky Natural Resource District) (Table 8). We were able to classify a relatively equal proportion of those sub-openings (38 in the Chilliwack Natural Resource District versus 46 in the Sea to Sky Natural Resource District) (Table 10), and found that, based on NAR, dispersed retention alone was applied in the Sea to Sky Natural Resource District far more frequently (26%) than in the Chilliwack Natural Resource District (5%). In the Chilliwack Natural Resource District, HVR was applied primarily as aggregated dispersed (32%) or group dispersed (37%) retention; the remaining third of harvesting was distributed relatively evenly across the other retention pattern classes. The dominant retention pattern classes in the Sea to Sky Natural Resource District were dispersed retention (26%), aggregated dispersed (35%), and group dispersed (24%) retention. Very little clearcut or aggregated retention occurred in this district.

Two of the seven HWR sub-openings (SOMP2) were classified as aggregated dispersed retention; the other five were unclassified (Table 11). Dispersed retention is expected to dominate the retention pattern in future HWR prescriptions due to the tree spacing practices (Table 4), although more tree aggregation may be used to increase windfirmness by clustering trees to maintain some mutual support. Wind damage assessment within the 1997–2011 HVR/HWR blocks must be made a priority in order to assess whether retention objectives are being met.

Ground-based yarding was the dominant yarding system for HVR in both the Chilliwack Natural Resource District and the Sea to Sky Natural Resource District (Table 12); it represented 74 and 65% of classified sub-openings, respectively, and created a range of retention patterns. Helicopter yarding was used more frequently in the Sea to Sky Natural Resource District than in the Chilliwack Natural Resource District: it represented 24% of classified sub-openings in the Sea to Sky Natural Resource District and was used to create dispersed and aggregated retention patterns (Table 12). Very little helicopter yarding was used in the Chilliwack Natural Resource District when implementing HVR. Cable yarding was not commonly used in the implementation of HVR, likely because of the easy terrain and operability of the drier ecosystems that were targeted for HVR between 1997 and 2011.

Future HWR harvesting will likely use a similar range of yarding systems to those under HVR because the SOMP2 practices do not restrict the harvesting system unless there is a shift in terrain types, such as steeper-sloped areas, that provide for HWR opportunities. All seven sub-openings implemented under HWR at the time of review involved ground-based yarding. On steeper slopes and in wetter areas, operational constraints may require the use of more cable yarding. This may represent a challenge to achieving single-

TABLE 12 *Summary of the number of heavy volume removal (HVR) sub-openings by retention pattern class and yarding system (for those HVR sub-openings that had a yarding system reported (n = 104)*

			Retention pattern class						
District[a]	Yarding System	Un-classified[b]	Aggregated retention	Dispersed retention	Aggregated dispersed retention	Group retention	Group dispersed retention	Clearcut	Total classified
Chilliwack	Cable	0	1	0	1	0	0	2	4
	Ground/cable	2	0	0	2	1	0	0	3
	Ground-based	8	0	2	9	2	13	2	28
	Helicopter	1	1	0	0	1	1	0	3
	Total	11	2	2	12	4	14	4	38
Sea to Sky	Cable	0	0	0	0	2	0	1	3
	Ground/cable	0	0	1	1	0	0	0	2
	Ground-based	0	0	7	13	2	8	0	30
	Helicopter	9	2	4	2	0	3	0	11
	Total	9	2	12	16	4	11	1	46

a The Sea to Sky Natural Resource District was formerly called the Squamish Forest District.

dispersed or aggregated tree retention due to cables damaging retention trees due to the need to meet worker safety requirements.

Stand ages were reported for 87 sub-openings, in total, for HVR and HWR. Overall, HVR was concentrated in mature forest (age class at harvest: 41–60 years [12%]; 61–140 years [70%]; 250+ years [18%]; $n = 80$ sub-openings). To the date of this review, SOMP2 HWR has focussed on younger stands; 71% of HWR harvesting was in stands 41–60 years of age, while 29% was in stands 141–250 years ($n=7$). Similar to HVR, however, HWR can be applied to stands of all ages, depending on cut allocation within the MFHA.

5 DISCUSSION AND CONCLUSIONS

The development of the SOMP1 harvesting practices for stand-level management of habitat for the endangered Northern Spotted Owl in coastal British Columbia's Chilliwack Natural Resource District and Sea to Sky Natural Resource District (SOMIT 1997a, 1997b) coincided with the development of alternative approaches to forestry (Franklin 1992). SOMP1 integrated two forest management approaches based on alternative forestry concepts. The first approach, light volume removal (LVR), prescribed partial cutting and thinning harvest entries and practices to improve owl habitat suitability by promoting stand attributes that are typical of mixed-species, later-successional stands (superior habitat). The second approach, heavy volume removal (HVR), prescribed retention of green trees and other forest attributes during regeneration harvesting in order to accelerate the development of future habitat attributes and their recruitment into the regenerating stand and the next rotation. A decade after its development and application, SOMP1 was replaced by SOMP2. LVR evolved into habitat enhancement practices (HEPs), which are intended to create superior habitat and enhance suitable habitat to superior habitat through the use of selection harvests. HVR evolved into harvest with

retention (HWR), which retains the use of a retention harvest system and associated practices to accelerate the recruitment of habitat attributes into the regenerating stand.

We undertook a comparative assessment of the two separate but related sets of guidelines and practices implemented under SOMP1 (1997–2010) and SOMP2 (2009 to present) as a first step in developing a monitoring framework to evaluate the effectiveness of the management of Spotted Owl habitat in British Columbia, and to assess improvements in SOMP2. Comparisons of the similarities and differences between the two plans proved challenging because the structure of the documentation for guidelines, best management practices, and GWMs differed, and clarifications about, or modifications to, practices discussed in the main body of the documents frequently appeared in appendices.

Practices under SOMP2 will likely continue to evolve, and an effectiveness monitoring framework will be used to document this evolution. Differences in the guidelines and practices of SOMP1 relative to SOMP2 are anticipated to result in differences in operational applications (i.e., silvicultural system or stand-tending approach), and thus differences in stand structure that affect subsequent stand development and long-term habitat outcomes. Of interest is whether these differences in applications and outcomes will produce significant differences in the enhancement and recruitment of the stand attributes of superior owl habitat, with SOMP2 potentially associated with more and better-quality habitat. Unlike SOMP1, where all practices were provided as operational guidelines, some of the SOMP2 practices are legal requirements (GWMs), and practitioners must ensure their correct interpretation. Therefore, it is important to have a clear understanding of the objectives, forest management approaches, and practices and targets of both SOMP1 and SOMP2. This report should assist with that understanding.

The comparative review presented in this report demonstrates that the move from SOMP1 to SOMP2 has produced some changes in, refinements to, and clarifications of, habitat management objectives, forest management approaches, and operational practices and targets. The changes were based on new data and research that had improved the overall knowledge of owl habitat requirements and forest dynamics and succession.

5.1 Habitat Management Objectives

Generally, there have been more substantial changes and revisions in the evolution from LVR to HEPs (Table 3) than from HVR to HWR (Table 5). HEPs objectives differ from those of LVR by requiring improvement in habitat quality to occur within 20 years of treatment while protecting the existing habitat quality of the stand, and HEPs do not enable harvesting within already superior habitat. HEPs are designed to be less prescriptive than LVR, and focus on achieving specified structural outcomes while providing operational flexibility.

Conversely, the HWR general objective of retaining structure to accelerate the recruitment of superior habitat attributes into the regenerating stand while supplying timber volume is the same as that for HVR. However, HWR has more potential, through its forest management approach and practices, to meet the habitat recruitment part of the objective because of its focus on inter-tree spacing and retention of large live trees for future wildlife tree recruitment.

Under SOMPs, wetter and drier ecosystem types have different habitat objectives for superior owl habitat (Table 1) and are managed slightly differently (Tables 2 and 4). However, SOMP1 implementation has focussed primarily on the drier ecotypes (Tables 9 and 10); little harvesting has been conducted in the wetter types. This may be a reflection of operability, access, jurisdiction (e.g., parks), and/or wood values. SOMP2 harvesting will be expected to include the wetter ecotypes, which is already evident in the limited amount of harvesting completed under HWR in the Chilliwack Natural Resource District (Table 11).

5.2 Light Volume Removal and Habitat Enhancement Practices

There are minor differences in forest management approaches between LVR and HEPs (Table 3). The management approaches diverge most substantially in the types of stands targeted for management. While LVR guidelines focussed on partial cutting through selection harvests of stands of all ages, along with the thinning of younger stands, HEPs guidance focusses on the use of selection harvests during the stem exclusion stage of stand development (60–140 years) (Table 3).

Our preliminary review demonstrates that the LVR forest management approach has been successfully implemented. LVR harvesting focussed on group selection through helicopter logging (~48% of NAR created under LVR), various forms of ground-based selection (~13%), and thinning of young stands (~27%) (Table 9). In practice, LVR focussed largely on the enhancement of owl habitat in mature and older forest (~86% of LVR harvesting was conducted in stands >80 years old). HEP harvesting had not been completed at the time of this preliminary review.

The SOMP2 HEPs do not focus explicitly on thinning younger, structurally simple plantations and stands (<60 years) to recruit owl habitat sooner, which was a focus under LVR and remains a focus in the U.S. Pacific Northwest (Anderson and Ronnenberg 2013). Use of thinning is not precluded under HEPs because the GWMs specify live-tree retention densities for homogenous canopies, although stand-tending treatments (e.g., spacing) are not covered. If more consideration is given to the use of stand-tending, such as thinning for restoring habitat, under SOMP2, the benefit will be improved flexibility in landscape spatial planning of long-term owl habitat.

Two key practice changes from LVR to HEPs that should result in differences in operational application and structural outcomes are:

1. a shift in harvest pattern from the predominant creation of yarding corridors under LVR to a focus on natural gap creation under HEPs.
    - This shift under HEPs is achieved through the harvesting of individual stems and very small groups of trees (<0.03ha) to mimic tree canopy gaps in order to simulate a more natural process of stand development, along with a cap on the area allowed for timber extraction corridors (≤25% basal area) (Table 2).
2. greater retention levels of large trees and wildlife trees under HEPs than under LVR, particularly in the wetter ecotypes, in order to avoid reducing habitat quality.
    - The combined changes from LVR to HEPs that are intended to achieve higher retention levels include specifying post-harvest large live-tree densities by diameter limit at levels that are consistent with

superior owl habitat, structuring the retention of large-diameter trees to better reflect the actual composition of the stand, and increasing wildlife tree density to reflect superior habitat condition.

At this point, we cannot determine if these HEPs changes will produce the desired improvement in outcomes. However, one-quarter of classified LVR harvesting (25% of NAR) had produced corridor patterns through harvesting (Table 9); another one-quarter of classified LVR harvesting (~27% of NAR) had thinned young stands by using linear corridors (Table 9). Research has illustrated the challenges this linear corridor yarding pattern poses for regeneration of desired owl habitat attributes such as Douglas-fir. This supports the changes under HEPs but requires monitoring.

The levels of tree retention under LVR were not evaluated in this review, but this will be an important part of future structural monitoring to evaluate SOMP effectiveness. However, HEPs should provide more operational flexibility in achieving their more stringent tree retention targets, given that they allow for a block-wide range in retention tree densities rather than the per-hectare basis required by LVR.

Yet, despite the revisions that enable flexibility in implementing HEPs in mature stands, and despite the large area of mature forest available for potentially applying HEPs (i.e., an estimated 12 953 ha of 60- to 140-year-old forest in LTOHAs) (Section 2), it may prove as challenging to apply HEPs as it was to apply LVR. The challenge of removing low volumes while meeting key habitat requirements, given possible operational access and topography limitations, meant that only a small area was harvested using LVR (the total area under prescription was 781 ha) (Table 8) during the SOMP1 10-year period, and a diversity of innovative harvest treatments (seven classes recorded during our review) was needed, with harvest patterns strongly tied to yarding corridors or helicopter logging. New research supports the ecological rationale of using gap harvesting, but information support for operational implementation continues to be lacking, and few experimental trials have been implemented in mature stands. Harvest systems such helicopter yarding are now more tractable for difficult landscapes, and were tried under LVR, but they can be costly; ground-based and cable-yarding systems will likely continue to be used for operational flexibility. HEPs have not yet been implemented; their implementation will be the real test of the newly proposed practices, given the practicalities of operational limitations.

5.3 Heavy Volume Removal and Harvest with Retention

As noted earlier, HVR and HWR have similar habitat management objectives, and both use reserves to recruit, and accelerate the development of, specific structural attributes that are not necessarily present in stands in a 60- to 100-year rotation. The main advancement of HWR over HVR was the establishment of the formal practice that no point within the block is more than a tree length (40 m) from a retained tree (Table 4); as such, HWR provides clear direction on the expected pattern of distribution, while allowing for flexibility to aggregate trees. Safety issues related to cable yarding on steep slopes may prevent retention directed under HWR from being met, but the alternative approach must demonstrate how the intent of the practice will be met. Practices under HWR also establish the role of retention of veteran and live dominant trees with defects for the recruitment of structural attributes of superior owl habitat for the longer term when the stand could provide owl

habitat. However, the high degree of variability in possible spatial patterns under both approaches may make comparative assessment difficult. In the review of SOMP1 HVR implementation, six harvest pattern classes were identified (including clearcut with no retention). While 80% of HVR harvesting (by NAR) (Table 10) contained some dispersed retention, only 20% of HVR harvesting (by NAR) was dispersed retention alone; it was frequently found in combination with either aggregated (< 0.25 ha; 32%) or group (≥ 0.25 ha; 28%) retention; further sub-divisions of these retention pattern classes may be required, depending on how the mixed retention affects stand and structural attribute development.

Although practices under HWR remain similar to those under HVR (Table 4), the following are some key differences for HWR:

1. No point within a block can be more than a tree length from a retained tree, given the retention system, which improves leave-tree distribution.
2. Planting of early-succession conifer species that are ecologically suited for the site is encouraged, and variable-density planting is considered, to address regeneration under the higher retention densities anticipated from a full retention system.
3. HWR specifies that long-lived, slow-decay tree species with high habitat value for Spotted Owl (i.e., Douglas-fir, western redcedar) be included in live-tree, wildlife-tree, and large downed wood retention.
4. HWR allows for the inclusion of dead, dying, or damaged wildlife trees into the large live-tree target, while HVR requires separate targeted retention of large, live, healthy trees versus wildlife trees (Table 5). Therefore, HWR has the potential to increase the density of live and dead wildlife trees through the inclusion of both veteran trees and large trees with defects among large live-tree retention targets, and the inclusion of snags in WTRAS.

Overall, HVR did not prove as difficult to apply as LVR: it comprised 74% of the sub-openings harvested under SOMP1, and a total area under prescription of 2136.7 ha (Table 8). Very little HWR had been completed at the time of this review, and even less harvesting information was available. However, we do not anticipate changes in the observed retention patterns established under HVR. Harvesting under HWR will continue to be dominated by dispersed, aggregated, and group retention, or combinations thereof, because it shares the structural retention objectives of HVR. In this respect HWR may not offer more flexibility in achieving large live-tree retention targets than HVR, because large live-tree densities have an expected pattern of distribution (i.e., no point within block > 40 m from tree). Most of the harvesting under HVR used ground-based systems. Implementation of regeneration harvests will likely remain similar under HWR.

Monitoring the implementation of HVR and HWR will require field assessment of structural attributes such as large live trees, wildlife trees, and snags relative to prescribed or desired targets, which is beyond the current scope of this review. However, we did find that HVR harvesting focussed primarily on stands > 60 years old, as intended in the operational guidelines: 70% of harvesting occurred in 60- to 140-year-old stands, whereas a minor amount (12%) occurred in young stands (age class of 41–60 years at time of harvest). New research continues to support the use of green-tree retention to develop some of the attributes associated with Spotted Owl habitat, such as diverse

canopies that include epicormic branching. However, field research has identified operational concerns regarding retention densities, including decline in retention due to wind and operational damage, reduced understorey growth, and undesired shifts in regeneration composition under retention canopies. HVR and HWR retention targets do not appear to be sufficiently high enough, based on current research, to buffer any loss due to windthrow or other types of leave-tree mortality; consequently, windthrow assessment should be an important aspect of HVR and HWR field monitoring. Subsequent management of the HWR retention blocks may be required to direct stand development toward a clearly defined target stand structure. This is not addressed explicitly by HWR (or by HEPs).

5.4 Large Woody Debris

Large coarse woody debris (CWD) is an important attribute of superior owl habitat; consequently, retention practices and targets for large CWD are specified in all forest-management approaches in both SOMP1 and SOMP2. However, the definition of large CWD for superior owl habitat and in SOMP1 is inconsistent with the definitions in the SOMP2 best management practices, which are inconsistent with the GWMs. Both LVR and HVR under SOMP1, and HEPs under SOMP2 require all pre-harvest CWD to be retained, but SOMP2 HWR sets a minimum retention volume to be met by both pre-harvest and, if required, post-harvest CWD. The difference between this minimum (75 m^3/ha) (Table 4) and that for superior habitat conditions in wet ecosystems (250 m^3/ha) (Table 1) is quite substantial, and relies more on recruitment over time to meet superior habitat conditions. Given all these issues, plus the potential for conflict with waste assessment and the importance of this attribute to owl prey species, field trials and effectiveness monitoring of large CWD targets and retention patterns over time will be extremely important, particularly under HWR.

5.5 Summary

In summary, this comparative review of SOMP guidelines and practices, and our preliminary review of SOMP implementation, begins the process of developing an effectiveness monitoring framework as part of the adaptive management approach (Nyberg 1999; Stankey et al. 2003) proposed under the Spotted Owl Management Plans and carried forward into the WHA Orders. Monitoring structural and biological outcomes is vital to assessing the effectiveness of practices for enhancing mature habitat for Spotted Owl under LVR and HEPs and of practices for accelerating the development of structural attributes associated with Spotted Owl habitat under HVR and HWR, and for identifying improvements in Spotted Owl habitat management under SOMP2. Development of an effectiveness monitoring framework that incorporates a standardized approach to characterizing post-harvest retention will be vital for comparing changes over time and between systems. Modelling the outcomes of implemented practices based on supporting research will provide a short-term assessment of the success in meeting objectives. Long-term monitoring should include indicators of core forest stand attributes associated with superior Spotted Owl habitat, and biological indicators that are expected to respond to changes in stand attributes. New information from research that supports restoration forestry, including the identification of retention thresholds to achieve desired outcomes, will continue to become available, given that forest restoration, with its multitude of objectives, has become a global topic of interest (Gustafsson et al. 2012; Stanturf et al. 2014).

APPENDIX 1 Wildlife Tree Classification used in Best Management Practices 2009 (adopted from the Forest Practices Code Biodiversity Guidebook [BC MOF and BC MOE 1995b])

Gradual death: conifers	General description of tree	Wildlife uses and users	Stages of decomposition
1	**live/healthy** — no decay	nesting; roosting; perching; territory; large-limb eagle and Osprey nests; raptors; scavengers; Great Blue Heron colonies; Marbled Murrelet	
2	**live/unhealthy** — internal decay or growth deformities (including insect damage, broken tops); dying tree	nests/roosts — PCEs[a] (strong excavators); SCUs[b]; large-limb nests; insect feeders	
3	**dead**[c] — hard heartwood; needles and twigs present; roots stable	nests/roosts — PCEs (strong excavators); SCUs; bats; large-limb nests; hunting/ hawking perches; branch roots; insect feeders	
4	**dead** — hard heartwood; no needles/twigs; 50% of branches lost; loose bark; top usually broken; roots stable	nests/roosts — PCEs (weaker excavators); SCUs; insect feeders	
5	**dead** — spongy heartwood; most branches/bark absent; internal decay; roots stable for larger trees; roots of smaller trees beginning to soften	nests/roosts — PCEs (weakest excavators); SCUs; bats; insect feeders; salamanders	

APPENDIX 1 Continued

6	**dead** — soft heartwood; no branches or bark; sapwood/ heartwood sloughing from upper bole; lateral roots of larger ones softening; smaller ones unstable	SCUs; insect feeders; salamanders; small mammals	
7-8	**dead** — soft heartwood; stubs; extensive internal decay; outer shell may be hard; lateral roots completely decomposed; hollow or nearly hollow shells	insect feeders; salamanders; small mammals	
9	**debris** — downed stubs or stumps	insect feeders; salamanders; small mammals; amphibians; drumming logs for grouse; flicker foraging; nutrient source	

a This classification system does not apply to downed logs and/or coarse woody debris.
b PCE = primary cavity excavator.
c SCU = secondary cavity user.
d The stability of dead trees is influences by the cause of death. Dead trees can be unstable if killed by butt rot or root rot, depending on the speces of the fungus. In general, *Phellinus* attack leads to instability, *Armillaria* attack must be assess carefully on a site-specific basis.

APPENDIX 2 List of abbreviations

CWD	coarse woody debris
GWM	General Wildlife Measure
HEPs	habitat enhancement practices
HVR	heavy volume removal
HWR	harvest with retention
LTOHA	Long-Term Owl Habitat Area
LVR	light volume removal
MFHA	Managed Future Habitat Area
NAR	net area to be reforested
SOMP1	Spotted Owl Management Plan 1
SOMP2	Spotted Owl Management Plan 2
SOMIT	Spotted Owl Management Inter-Agency Team
TAUP	total area under prescription
WHA	Wildlife Habitat Area
WTRA	Wildlife Tree Retention Area

LITERATURE CITED

Acker, S.A., E.K. Zenner, and W.H. Emmingham. 1998. Structure and yield of two-aged stands on the Willamette National Forest, Oregon: implications for green tree retention. Can. J. For. Res. 28(5):749–758.

Amaranthus, M., J.M. Trappe, L. Bednar, and D. Arthur. 1994. Hypogeous fungal production in mature Douglas-fir forest fragments and surrounding plantations and its relation to coarse woody debris and animal mycophagy. Can. J. For. Res. 24(11):2157–2165.

Anderson, P.D. and K.L. Ronnenberg (editors). 2013. Density management in the 21st century: west side story. U.S. Dep. Agric. For. Serv., Portland, Oreg. Gen. Tech. Rep. PNW-GTR-880.

Andrews, L.S., J.P. Perkins, J.A. Thrailkill, N.J. Poage, and J.C. Tappeiner. 2005. Silvicultural approaches to develop Northern Spotted Owl nesting sites, Central Coast Ranges, Oregon. West. J. Appl. For. 20(1):13–27.

Barbour, R.J., S. Johnson, J.P. Hayes, and G.F. Tucker. 1997. Simulated stand characteristics and wood product yields from Douglas-fir plantations managed for ecosystem objectives. For. Ecol. Manag. 91(2):205–219.

Beese, W.J. 2009. A decade of variable retention in Coastal BC: What have we learned? Presentation to the Coastal Silviculture Committee, Feb. 12, 2009. www.coastalsilviculturecommittee.com/Summer%202009/VR-DecadeLearnings-CSC2009-Beese.pdf

Birch, K.R. and K.N. Johnson. 1992. Stand-level wood-production costs of leaving live, mature trees at regeneration harvest in coastal Douglas-fir stands. West. J. Appl. For. 7(3):65–68.

British Columbia Ministry of Forests (BC MOF). 2003. Silvicultural systems handbook for British Columbia. For. Pract. Br., Victoria, B.C. www.for.gov.bc.ca/hfp/publications/00085/silvsystemshdbk-web.pdf

_____. 2005. Provincial logging residue and waste measurement procedures manual. Revenue Br., Victoria, B.C. www.for.gov.bc.ca/hva/manuals/rwprocedures.htm

British Columbia Ministry of Forests and British Columbia Ministry of Environment (BC MOF and BC MOE). 1995a. Silvicultural systems guidebook, April 1995. B.C. Min. For., For. Pract. Br., Victoria, B.C. Forest Practices Code of British Columbia Guidebook. www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/system/sstoc.htm

_____. 1995b. Biodiversity guidebook, April 1995. B.C. Min. For., For. Pract. Br., Victoria, B.C. Forest Practices Code of British Columbia Guidebook. www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/biodiv/biotoc.htm

_____. 1995c. Riparian management area guidebook, December 1995. B.C. Min. For., For. Pract. Br., Victoria, B.C. Forest Practices Code of British Columbia Guidebook. www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/riparian/rip-toc.htm

British Columbia Ministry of Forests and Range (BC MOFR). 2008. Glossary of forestry terms in British Columbia. Victoria, B.C. www.for.gov.bc.ca/hfd/library/documents/glossary/Glossary.pdf

British Columbia Ministry of Forests, Lands and Natural Resource Operations (BCFLNR). 2010. Chief Forester's guidance on coarse woody debris management. May 2010. Victoria, B.C. www.for.gov.bc.ca/hfp/values/wildlife/wlt/policies.htm

_____. 2011. Order—Wildlife Habitat Areas 2-494 to 2-510. Victoria, B.C. www.env.gov.bc.ca/wld/documents/wha/SPOW_2-494-510_Order.pdf

_____. 2013. Order—Wildlife Habitat Areas 2-517 to 2-525. Surrey, B.C. www.env.gov.bc.ca/wld/documents/wha/SPOW_WHA_2-517%20to%202-525_Order.pdf

Brodie, L.S. and D.S. DeBell. 2013. Residual densities affect growth of overstory trees and planted Douglas-fir, western hemlock, and western redcedar: results from the first decade. West. J. Appl. For. 28(3):121–127.

Bunnell, F.L. 2013. Sustaining cavity-using species: patterns of cavity use and implications to forest management. Int. Scholarly Res. Notices For. 2013:457698. www.hindawi.com/journals/isrn/2013/457698

Busby, P.E., P. Adler, T.L. Warren, and F.J. Swanson. 2006. Fates of live trees retained in forest cutting units, western Cascade Range, Oregon. Can. J. For. Res. 36(10):2550–2560.

Busing, R.T. and S.L. Garman. 2002. Promoting old-growth characteristics and long-term wood production in Douglas-fir forests. For. Ecol. Manag. 160(1):161–175.

Carey, A.B. 1995. Sciurids in Pacific Northwest managed and old-growth forests. Ecol. Appl. 5(3):648–661.

Carey, A.B., S.P. Horton, and B.L. Biswell. 1992. Northern Spotted Owls: influence of prey base and landscape character. Ecol. Monogr. 62(2): 223–250.

Carey, A.B. and M.L. Johnson. 1995. Small mammals in managed, naturally young, and old-growth forests. Ecol. Appl. 5(2):336–352.

Carey, A.B., D.R. Thysell, and A.W. Brodie. 1999. The forest ecosystem study: background, rationale, implementation, baseline conditions, and silvicultural assessment. U.S. Dep. Agric. For. Serv., Portland, Oreg. Gen. Tech. Rep. PNW-GTR-457.

Carey, A.B., D.R. Thysell, L. Villa, T. Wilson, S. Wilson, J.M. Trappe, and W. Colgan. 1996. Foundations of biodiversity in managed Douglas-fir forests. In: The role of restoration in ecosystem management. Proc. 2nd Symp. Ecol. Restoration, Sept. 14–17, 1995, Seattle, Wash., pp. 68–82. Soc. Ecol. Restoration, Madison, Wis.

Chutter, M.J., I. Blackburn, D. Bonin, J. Buchanan, B. Costanzo, D. Cunnington, A. Harestad, T. Hayes, D. Heppner, L. Kiss, J. Surgenor, W. Wall, L. Waterhouse, and L. Williams. 2004. Recovery strategy for the Northern Spotted Owl (*Strix occidentalis caurina*) in British Columbia. B.C. Min. Environ., Victoria, B.C. Prepared by the Spotted Owl Recovery Team. www.sararegistry.gc.ca/default.asp?lang=En&n=67397DA1-1

Comfort, E.J., S.D. Roberts, and C.A. Harrington. 2010. Midcanopy growth following thinning in young-growth conifer forests on the Olympic Peninsula western Washington. For. Ecol. Manag. 259(8):1606–1614.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2015. Spotted Owl | *Strix occidentalis caurina*. Can. Wildl. Serv., Environ. Can., Ottawa, Ont. www.cosewic.gc.ca/eng/sct1/searchdetail_e.cfm?id=33&StartRow=1&boxStatus=All&boxTaxonomic=All&location=All&change=All&board=All&commonName=northern%20spotted%20owl&scienceName=&returnFlag=0&Page=1

D'Anjou, B. 1998. Partial cutting in the coast-interior transition: seedfall, regeneration, and stand structure changes. In: Managing the dry Douglas-fir forests of the Southern Interior: workshop proceedings, Apr. 29–30, 1997, Kamloops, B.C. A. Vyse, D.C. Hollstedt, and D.J. Huggard (editors). B.C. Min. For., Res. Br., Victoria, B.C. For. Sci. Program Work. Pap. 34, pp. 21–28.

_____. 2002. Roberts Creek Study Forest: harvesting, windthrow and conifer regeneration within alternative silvicultural systems in Douglas-fir dominated forests on the Sunshine Coast. B.C. Min. For., Vancouver For. Reg., Nanaimo, B.C. Tech. Rep. TR-018 Silviculture. www.for.gov.bc.ca/rco/research/projects%5Crcsf%5Ctr018.pdf

_____. 2003. Single-tree and group selection harvesting in an old-growth forest on the west coast of Vancouver Island, British Columbia. B.C. Min. For., Vancouver For. Reg., Nanaimo, B.C. Tech. Rep. TR-024 Silviculture. www.for.gov.bc.ca/rco/research/silvreports/tr024.pdf

_____. 2007. Dispersed retention in the Coast–Interior transition: stand structure and regeneration 15 years after harvest. In: Overcoming obstacles to variable retention in forest management. Science to Management Forum Proc., Sept. 25–27, 2007. B.C. J. Ecosystems Manag. 8(3):131–135. http://forrex.org/sites/default/files/publications/jem_archive/ISS42/vol8_no3_scienceforum.pdf

D'Anjou, B., R. Parrish, and L. Waterhouse. 2006. Silvicultural treatments for enhancing and recruiting Spotted Owl habitat in British Columbia. B.C. Min. For. Range, Coast For. Reg., Res. Section, Nanaimo, B.C. Tech. Rep. TR-033 Silviculture. www.for.gov.bc.ca/rco/research/silvreports/tr033.pdf

Day, K., C. Koot, and A. Wiensczyk. 2011. The shelterwood silvicultural system in British Columbia—a practitioner's guide part 3: operational implementation. J. Ecosystems Manag. 12(2):95–106.

de Montigny, L. 2004. Silviculture Treatments for Ecosystem Management in the Sayward (STEMS): establishment report for STEMS 1, Snowden Demonstration Forest. B.C. Min. For., Res. Br., Victoria, B.C. For. Sci. Program Tech. Rep. 017. www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr017.htm

de Montigny, L. and G.D. Nigh. 2009. Silviculture Treatments for Ecosystem Management in the Sayward (STEMS): establishment report for STEMS 2, Elk Bay. B.C. Min. For., Range, Res. Br., Victoria, B.C. For. Sci. Program Tech. Rep. 049. www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr049.htm

Densmore, N. 2011. Coast Forest Region: analysis of stand-level biodiversity sampling results in six predominant biogeoclimatic subzones. B.C. Min. For., Lands Nat. Resource Ops., For. Pract. Investment Br., Victoria, B.C. For. Range Eval. Program Rep. 30. www.for.gov.bc.ca/ftp/hfp/external/!publish/FREP/reports/FREP_Report_30.pdf

Dodson, E.K., A. Ares, and K.J. Puettmann. 2012. Early responses to thinning treatments designed to accelerate late successional forest structure in young coniferous stands of western Oregon, U.S. Can. J. For. Res. 42(2):345–355.

Fan, Z., S.R. Shifley, M.A. Spetich, F.R. Thompson, and D.R. Larsen. 2003. Distribution of cavity trees in midwestern old-growth and second-growth forests. Can. J. For. Res. 33(8):1481–1494.

Forsman, E.D. and A.R. Giese. 1997. Nests of Northern Spotted Owls on the Olympic Peninsula, Washington. Wilson Bull. 109(1):28–41.

Franklin, J.F. 1989. Toward a new forestry. Am. For. 95(11/12):37–44.

_____. 1992. Scientific basis for new perspectives in forests and streams. In: Watershed management: balancing sustainability and environmental change. R.J. Naiman (editor). Springer, New York, N.Y., pp. 25–72.

Franklin, J.F., D.R. Berg, D.A. Thornburgh, and J.C. Tappeiner. 1997. Alternative silvicultural approaches to timber harvesting: variable retention harvest systems. In: Creating a forestry for the 21st century: the science of ecosystem management. K.A. Kohn and J.A. Franklin (editors). Island Press, Washington, D.C., pp. 111–139.

Franklin, J.F. and K.A. Kohm (editors). 1997. Creating a forestry for the 21st century: the science of ecosystem management. Island Press, Washington, D.C.

Franklin, J.F., T.A. Spies, R.V. Pelt, A.B. Carey, D.A. Thornburgh, D.R. Berg, and J. Chen. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. For. Ecol. Manag. 155(1):399–423.

Garber, S., T.Y. Lam, and D.A. Maguire. 2011. Growth and mortality of residual Douglas-fir after regeneration harvests under group selection and two-story silvicultural systems. West. J. Appl. For. 26(2):64–70.

Garman, S.L., J.H. Cissel, and J.H. Mayo. 2003. Accelerating development of late-successional conditions in young managed Douglas-fir stands: a simulation study. U.S. Dep. Agric. For. Serv., Portland, Oreg. Gen. Tech. Rep. PNW-GTR-557. http://andrewsforest.oregonstate.edu/pubs/pdf/pub2722.pdf

Gomez, D.M., R.G. Anthony, and J.P. Hayes. 2005. Influence of thinning of Douglas-fir forests on population parameters and diet of northern flying squirrels. J. Wildl. Manag. 69(4):1670–1682.

Gray, A.N. and T.A. Spies. 1996. Gap size, within-gap position and canopy structure effects on conifer seedling establishment. J. Ecol. 84(5):635–645.

Gray, A.N., T.A. Spies, and R.J. Pabst. 2012. Canopy gaps affect long-term patterns of tree growth and mortality in mature and old-growth forests in the Pacific Northwest. For. Ecol. Manag. 281:111–120.

Green, R. and K. Klinka. 1994. A field guide to site identification and interpretation for the Vancouver Forest Region. B.C. Min. For., Res. Program, Victoria, B.C. Land Manag. Handb. 28. www.for.gov.bc.ca/hfd/pubs/docs/lmh/lmh28/lmh28-01.pdf

Gustafsson, L., S.C. Baker, J. Bauhus, W.J. Beese, A. Brodie, J. Kouki, and J.F. Franklin. 2012. Retention forestry to maintain multifunctional forests: a world perspective. BioScience 62(7):633 –645.

Hansen, A.J., S.L. Garman, J.F. Weigand, D.L. Urban, W.C. McComb, and M.G. Raphael. 1995. Alternative silvicultural regimes in the Pacific Northwest: simulations of ecological and economic effects. Ecol. Appl. 5(3):535–554.

Hayes, J.P., S.S. Chan, W.H. Emmingham, J.C. Tappeiner, L.D. Kellogg, and J.D. Bailey. 1997. Wildlife response to thinning young forests in the Pacific Northwest. J. For. 95(8):28–33.

Haynes, R.W. 2001. Overview. In: Northwest Forest Plan research synthesis. R.W. Haynes and G.E. Perez (editors). U.S. Dep. Agric. For. Serv., Portland, Oreg. Gen. Tech. Rep. PNW-GTR-498, pp. 2–9.

Holloway, G. L. and W.P. Smith. 2011. A meta-analysis of forest age and structure effects on northern flying squirrel densities. J. Wildl. Manag. 75(3):668–674.

Holloway, G.L., W.P. Smith, C.B. Halpern, R.A. Gitzen, C.C. Maguire, and S.D. West. 2012. Influence of forest structure and experimental green-tree retention on northern flying squirrel (*Glaucomys sabrinus)* abundance. For. Ecol. Manag. 285:187–194.

Hollstedt, C. and A. Vyse (editors). 1997. Sicamous Creek silvicultural systems project: workshop proceedings. Apr. 24–25, 1996, Kamloops, B.C. B.C. Min. For., Res. Br., Victoria, B.C. Work. Pap. 24/1997. http://wetbelt.unbc.ca/docs/Wp24.pdf

Huggard, D. and L. Kremsater. 2007. Quantitative synthesis of rates for projecting deadwood in BC forests. For. Sci. Program, Victoria, B.C. For. Investment Account Tech Rep. www.for.gov.bc.ca/hfd/library/FIA/2008/FSP_So84000a.pdf

Hunter, M.G. (editor). 1993. Young managed stands. Dep. For. Sci., Oregon State Univ., Corvallis, Oreg.; Pac. N.W. Res. Stn., Corvallis, Oreg.; Willamette Natl. For., Blue River, Oreg. Cascade Cent. Ecosystem Manag. Communique 3.

Isaac, L.A. 1956. Place of partial cutting in old-growth stands of the Douglas-fir region. U.S. Dep. Agric., For. Serv., Portland, Oreg. Res. Pap. 16. www.fs.fed.us/pnw/pubs/pnw_os_rp-16.pdf

Keeton, W.S. and J.F. Franklin. 2005. Do remnant old-growth trees accelerate rates of succession in mature Douglas-fir forests? Ecol. Monogr. 75(1):103–118.

Long, J.N. and S.D. Roberts. 1992. Growth and yield implications of a "New Forestry" silvicultural system. West. J. Appl. For. 7(1):6–9.

Maguire, D.A., C.B. Halpern, and D.L. Phillips. 2007. Changes in forest structure following variable-retention harvests in Douglas-fir dominated forests. For. Ecol. and Manag. 242(2):708–726.

Manning, T., J.C. Hagar, and B.C. McComb. 2012. Thinning of young Douglas-fir forests decreases density of northern flying squirrels in the Oregon Cascades. For. Ecol. Manag. 264:115–124.

McComb, W.C., T.A. Spies, and W.H. Emmingham. 1993. Douglas-fir forests: managing for timber and mature-forest habitat. J. For. 91(12):31–42.

Meidinger, D. and J. Pojar (editors). 1991. Ecosystems of British Columbia. B.C. Min. For. Range, Res. Br., Victoria, B.C. Spec. Rep. Ser. 6. www.for.gov.bc.ca/hfd/pubs/Docs/Srs/Srs06.htm

Meiman, S., R.A. Anthony, E. Glenn, T. Bayless, A. Ellingson, M.C. Hansen, and C. Smith. 2003. Effects of commercial thinning on home-range and habitat-use patterns of a male Northern Spotted Owl: a case study. Wildl. Soc. Bull. 31(4):1254–1262.

Miller, R.E., J. Smith, P.W. Adams, and H.W. Anderson. 2007. Growth of Douglas-fir near equipment trails used for commercial thinning in the Oregon Coast Range. U.S. Dep. Agric., For. Serv., Portland, Oreg. Res. Pap. PNW-RP-574. www.fs.fed.us/pnw/pubs/pnw_rp574.pdf

North, M., J. Trappe, and J. Franklin. 1997. Standing crop and animal consumption of fungal sporocarps in Pacific Northwest forests. Ecology 78(5):1543–1554.

Nyberg, B. 1999. An introductory guide to adaptive management for project leaders and participants. B.C. Min. For., For. Pract. Br., Victoria, B.C. http://planet.uwc.ac.za/NISL/ESS/ESS121/Introductory-Guide-AM.pdf

Oliver, C.D. and B.C. Larson. 1990. Forest stand dynamics. Update ed. John Wiley & Sons, Inc., New York, N.Y.

Passmore, J. A. 2007. Response of seedlings and saplings to canopy gaps in coastal old growth forests. PhD thesis. Simon Fraser Univ., Burnaby, B.C.

Poage, N.J. and P.D. Anderson. 2007. Large-scale silviculture experiments of western Oregon and Washington. U.S. Dep. Agric., For. Serv., Portland, Oreg. Gen. Tech. Rep. PNW-GTR-713. www.arlis.org/docs/vol1/156463082.pdf

Province of British Columbia. 1993. Bill 56 *Forest Amendment Act* No. 2, 1993. Victoria, B.C. www.leg.bc.ca/35th2nd/3rd_read/gov56-3.htm

_____. 1996. *Forest Practices Code of British Columbia Act* 1996. Victoria, B.C. www.bclaws.ca/Recon/document/ID/freeside/00_96159_01

_____. 1998a. Operational and Site Planning Regulation B.C. Reg. 107/98. Victoria, B.C. Deposited April 2, 1998 O.C. 0426/98. Effective June 15, 1998. www.for.gov.bc.ca/tasb/legsregs/archive/fpc/fpcaregs/oplanreg/opr.htm

_____. 1998b. *Workers Compensation Act*, Occupational Health and Safety Regulation, BC Reg 296/97. Part 26, Forestry operations and similar activities—Section 26.11, Dangerous trees. Victoria, B.C. Effective April 15, 1998. www.bclaws.ca/civix/document/id/complete/statreg/296_97_21

_____. 2004. *Forest and Range Practices Act* 2004. [SBC 2002] Chapter 69. Victoria, B.C. Assented to November 21, 2002. www.bclaws.ca/Recon/document/ID/freeside/00_02069_01

Ransome, D.B., P.M. Lindgren, M.J. Waterhouse, H.M. Armleder, and T.P. Sullivan. 2009. Small-mammal response to group-selection silvicultural systems in Engelmann spruce–subalpine fir forests 14 years postharvest. Can. J. For. Res. 39(9):1698–1708.

Remm, J. and A. Lõhmus. 2011. Tree cavities in forests—the broad distribution pattern of a keystone structure for biodiversity. For. Ecol. Manag. 262(4):579–585.

Roberts, S.D. and C.A. Harrington. 2008. Individual tree growth response to variable-density thinning in coastal Pacific Northwest forests. For. Ecol. Manag. 255(7):2771–2781.

Rollerson, T.P., C.M. Peters, and W.J. Beese. 2009. Variable retention windthrow monitoring project 2001 to 2009. B.C. Min. For., Lands Nat. Resource Ops., Victoria, B.C. For. Investment Account, Final Rep. www.coastalsilviculturecommittee.com/Summer%202009/VR_Windthrow_Monitoring-BBeeze.pdf

Rose, C.R. and P.S. Muir. 1997. Green-tree retention: consequences for timber production in forests of the western Cascades, Oregon. Ecol. Appl. 7(1):209–217.

Schliemann, S.A. and J.G. Bockheim. 2011. Methods for studying treefall gaps: a review. For. Ecol. Manag. 261(7):1143–1151.

Smith, N.J. and W.J. Beese. 2012. Effects of low levels of dispersed retention on the growth and survival of young, planted Douglas-fir. Forests 3(2):230–243. www.mdpi.com/1999-4907/3/2/230/htm

Spies, T.A. and J.F. Franklin. 1991. The structure of natural young, mature, and old-growth Douglas-fir forests in Oregon and Washington. In: Wildlife and vegetation of unmanaged Douglas-fir forests. U.S. Dep. Agric. For. Serv., Portland, Oreg. Gen. Tech. Rep. PNW-GTR-285, pp. 91–111. http://andrewsforest.oregonstate.edu/pubs/pdf/pub1244.pdf

Spies, T.A., J.F. Franklin, and M. Klopsch. 1990. Canopy gaps in Douglas-fir forests of the Cascade Mountains. Can. J. For. Res. 20(5):649–658.

Spotted Owl Best Management Practices Working Group. 2009. Best management practices for managing Spotted Owl habitat: a component of the Spotted Owl Management Plan 2. B.C. Min. For. Range, Coast For. Reg., Chilliwack For. Distr., Squamish For. Distr., Nanaimo, B.C., and B.C. Min. Environ., Victoria, B.C. www.env.gov.bc.ca/esd/distdata/ecosystems/frpa/Approved_FRPR_sec7_WLPPR_sec9_Notices_and_Supporting_Info/Species_at_Risk/Chilliwack_FD/Supporting_info/Docs/SPOW_2009/SPOWBestManagementPractiesJul2009.pdf

Spotted Owl Management Inter-Agency Team (SOMIT). 1997a. Spotted Owl Management Plan—strategic component. B.C. Min. Environ., Lands and Parks and B.C. Min. For., Victoria, B.C. www.for.gov.bc.ca/hfd/library/documents/bib86853.pdf

_____. 1997b. Managing Spotted Owl habitat: operational guidelines component of the Spotted Owl Management Plan. B.C. Min. Environ., Lands and Parks and B.C. Min. For., Victoria B.C. www.env.gov.bc.ca/esd/distdata/ecosystems/frpa/Approved_FRPR_sec7_WLPPR_sec9_Notices_and_Supporting_Info/Species_at_Risk/Chilliwack_FD/Supporting_info/Docs/SPOW_2009/OperationalGuidelinesComp_SOMP_1997.pdf

_____. 1999. Spotted Owl Management Plan—Resource Management Plan, Chilliwack Forest District, May 1999. B.C. Min. Environ., Lands and Parks and B.C. Min. For., Victoria, B.C.

Stan, A.B. and L.D. Daniels. 2010. Growth releases of three shade-tolerant species following canopy gap formation in old-growth forests. J. Vegetation Sci. 21(1):74–87.

_____. 2014. Growth releases across a natural canopy gap-forest gradient in old-growth forests. For. Ecol. Manag. 313:98–103.

Stankey, G.H., B.T. Bormann, C. Ryan, B. Shindler, V. Sturtevant, R.N. Clark, and C. Philpot. 2003. Adaptive management and the Northwest Forest Plan: rhetoric and reality. J. For. 101(1):40–46.

Stanturf, J.A., B.J. Palik, and R.K. Dumroese. 2014. Contemporary forest restoration: a review emphasizing function. For. Ecol. Manag. 331:292–323.

Stathers, R.J., T.P. Rollerson, and S.J. Mitchell. 1994. Windthrow handbook for British Columbia forests. B.C. Min. For., Res. Br., Victoria, B.C. Work. Pap. 9401. http://deanellis.ca/alldocs/24%20Windrow%20Handbook.pdf

Sutherland, G.D., D. O'Brien, A. Fall, E.L. Waterhouse, A.S. Harestad, and J.B. Buchanan. 2007. A framework to support landscape analyses of habitat supply and effects on populations of forest-dwelling species: a case study based on the Northern Spotted Owl. B.C. Min. For. Range, Res. Br., Victoria, B.C. Tech. Rep. 038. www.for.gov.bc.ca/hfd/pubs/Docs/TR/Tr038.htm

Temesgen, H., T.M. Barrett, and G. Latta. 2008. Estimating cavity tree abundance using nearest neighbor imputation methods for western Oregon and Washington forests. Silva Fennica 42(3):337–354.

Thomas, J.W., E.D. Forsman, J.B. Lint, E.C. Meslow, B.B. Noon, and J. Verner. 1990. A conservation strategy for the Northern Spotted Owl. Report to the Interagency Scientific Committee to address the conservation of the Northern Spotted Owl. U.S. Dep. Agric., For. Serv., Portland, Oreg. www.fws.gov/wafwo/species/Fact%20sheets/NSO%20Interagency%20Conservation%20Strategy.pdf

United States Department of Agriculture and United States Department of the Interior (USDA and USDI). 1994a. Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the Northern Spotted Owl. For. Serv., Bureau Land Manag., Washington, D.C. www.blm.gov/or/plans/nwfpnepa/FSEIS-1994/newroda.pdf

_____. 1994b. Standards and guidelines for management of habitat for late-successional and old-growth forest related species within the range of the Northern Spotted Owl—Attachment A to the record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the Northern Spotted Owl. For. Serv., Bureau Land Manag., Washington, D.C. www.reo.gov/library/reports/newsandga.pdf

Urgenson, L.S., C.B. Halpern, and P.D. Anderson. 2012. Twelve-year responses of planted and naturally regenerating conifers to variable-retention harvest in the Pacific Northwest, U.S. Can. J. For. Res. 43(999):46–55. www.researchgate.net/publication/236833144

_____. 2013. Level and pattern of overstory retention influence rates and forms of tree mortality in mature, coniferous forests of the Pacific Northwest, U.S. For. Ecol. Manag. 308:116–127.

Verschuyl, J., S. Riffell, D. Miller, and T.B. Wigley. 2011. Biodiversity response to intensive biomass production from forest thinning in North American forests—a meta-analysis. For. Ecol. Manag. 261(2):221–232.

Walter, S.T. and C.C. Maguire. 2004. Conifer response to three silvicultural treatments in the Oregon Coast Range foothills. Can. J. For. Res. 34(9):1967–1978.

Waterhouse, F.L., I.A. Manley, A.S. Harestad, and P.K. Ott. 2012. Nest structures and habitats of the Northern Spotted Owl in three ecological subregions of British Columbia. Prov. B.C., Victoria, B.C. Tech. Rep. 069. www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr069.htm

White, B. (editor). 2011. Revised recovery plan for the Northern Spotted Owl (*Strix occidentalis caurina*). U.S. Fish Wildl. Serv., Portland, Oreg.

Wilson, T.M. and E.D. Forsman. 2013. Thinning effects on Spotted Owl prey and other forest-dwelling small mammals. In: Density management in the 21st century: west side story P.D. Anderson and K.L. Ronnenberg (editors). U.S. Dep. Agric., For. Serv., Portland Oreg. Gen. Tech. Rep. PNW-GTR-880, pp. 79–90. www.fs.fed.us/pnw/pubs/pnw_gtr880.pdf

Zenner, E.K. 2000. Do residual trees increase structural complexity in Pacific Northwest coniferous forests? Ecol. Appl. 10(3):800–810.

Zenner, E.K., S.A. Acker, and W.H. Emmingham. 1998. Growth reduction in harvest-age, coniferous forests with residual trees in the western central Cascade Range of Oregon. For. Ecol. Manag. 102(1):75–88.